ASTRONOMY

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What We Know About Saturn

Meade System 2000

Think of the dimensions a truly research-quality instrument would add to your observing program.

Then consider moving up to the quality and performance of a Meade 4-inch or 8-inch Schmidt-Cassegrain. For Meade Schmidt-Cassegrains, both optically and mechanically, really are the finest instruments of their kind ever offered the serious observer and astrophotographer.

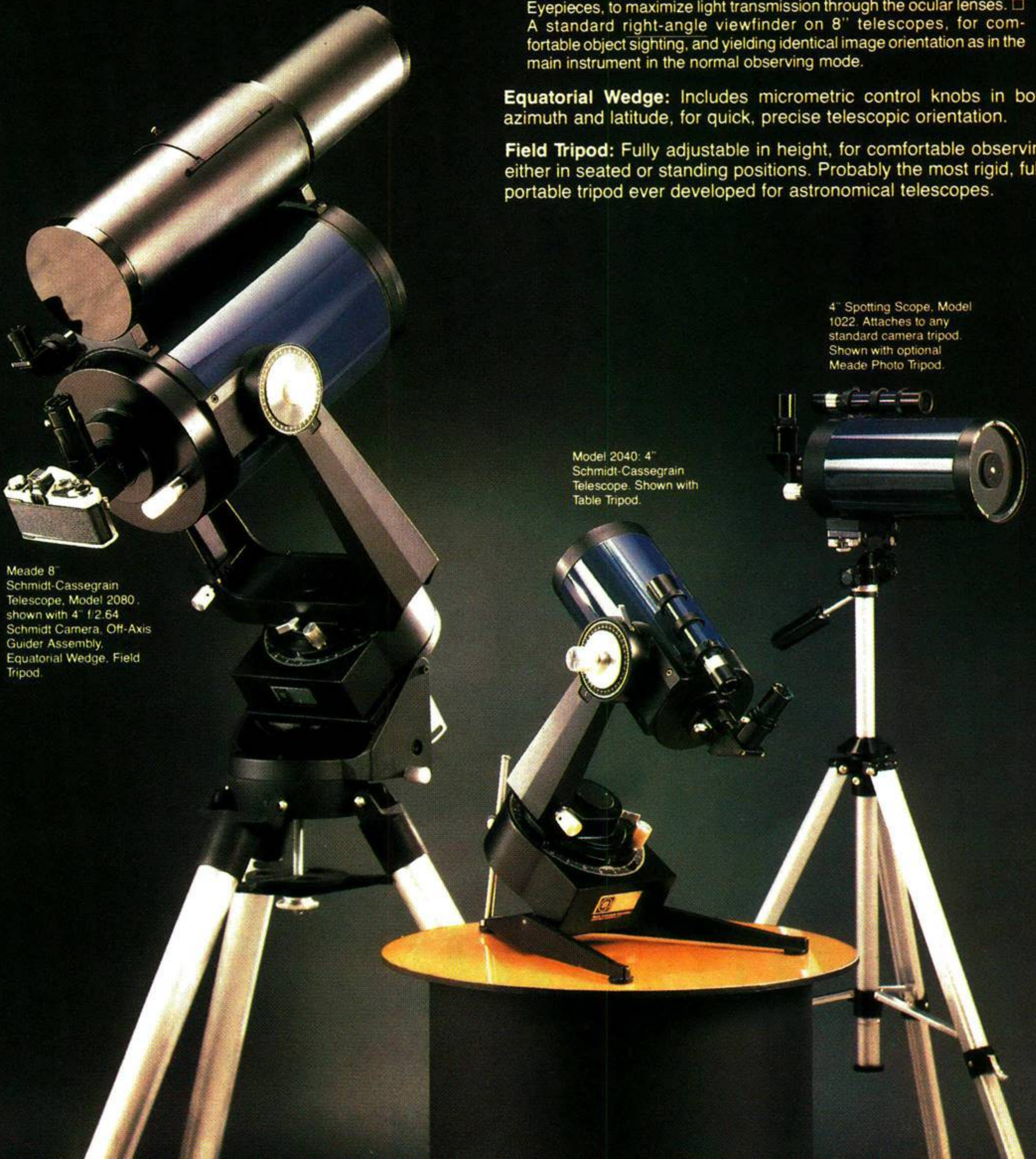
And, as parts of a wide-ranging system, they are instruments that will grow with your expanding horizons.

Standard Equipment: No other commercially available Schmidt-Cassegrains offer such a list of important technical advantages, much less as standard equipment included in the Base Price:

> Worm gear drive systems, on both 4" and 8" models, for extremely low photo-visual periodic error and zero backlash. ☐ Ball bearings on both Declination and Polar Axes, permitting microsmooth tracking and precise balancing, even with the addition of auxiliary systems on the main telescope. ☐ On 8" models, an oversize 8.25" primary mirror, for a wider fully illuminated field, and to reduce the "edge darkening" of Schmidt-Cassegrains which use standard 8" diameter primaries. ☐ Multi-Coated Eyepieces, to maximize light transmission through the ocular lenses. ☐ A standard right-angle viewfinder on 8" telescopes, for comfortable object sighting, and yielding identical image orientation as in the main instrument in the normal observing mode.

Equatorial Wedge: Includes micrometric control knobs in both azimuth and latitude, for quick, precise telescopic orientation.

Field Tripod: Fully adjustable in height, for comfortable observing either in seated or standing positions. Probably the most rigid, fully portable tripod ever developed for astronomical telescopes.



4" Spotting Scope, Model 1022. Attaches to any standard camera tripod. Shown with optional Meade Photo Tripod.

Model 2040: 4" Schmidt-Cassegrain Telescope. Shown with Table Tripod.

Meade 8" Schmidt-Cassegrain Telescope, Model 2080, shown with 4" f/2.64 Schmidt Camera, Off-Axis Guider Assembly, Equatorial Wedge, Field Tripod.

Schmidt-Cassegrains

The System: Perhaps most importantly of all, Meade System 2000 Schmidt-Cassegrains are part of a wide and versatile system: the amazing 4" f/2.64 Schmidt Camera; 4" Schmidt-Cassegrain Photo-Guide Telescope with Illuminated Reticle Eyepiece; Dual-Axis Drive Corrector, and more — all of which attach easily and directly to 8" models.

Aesthetic Design: In the beauty of their enameled deep-blue tube surfaces, in the fineness of their machine-tooled mechanical components, Meade System 2000 models are light years ahead of the competition. See the System 2000 for yourself, and no further explanation will be necessary.

Warranty: As with all Meade products, the System 2000 is fully covered by the Meade One-Year Limited Warranty. See the Meade catalog for full details on this no-risk protection of your investment.

PRICE LIST

Model 2040:	
4" Schmidt-Cassegrain Telescope with Fork Mount ...... Base Price	**$545**
Model 2080:	
8" Schmidt-Cassegrain Telescope with Fork Mount ...... Base Price	**785**
Equatorial Wedge 4"/8"	**50**
Field Tripod 4"/8"	**140**
Table Tripod 4"	**35**
Table Tripod 8"	**45**
Model 1020: 1000mm f/10 Telephoto Lens	**325**
Model 1022: 4" Spotting Scope	**395**
Meade Photo Tripod for Models 1020 or 1022	**50**
Model 2066: 4" f/2.64 Schmidt Camera	**435**

All prices include packing. Complete telescopes are packed in luggage-quality foam-lined carrying cases. All prices F.O.B. Costa Mesa, California. Calif. residents add 6% sales tax.

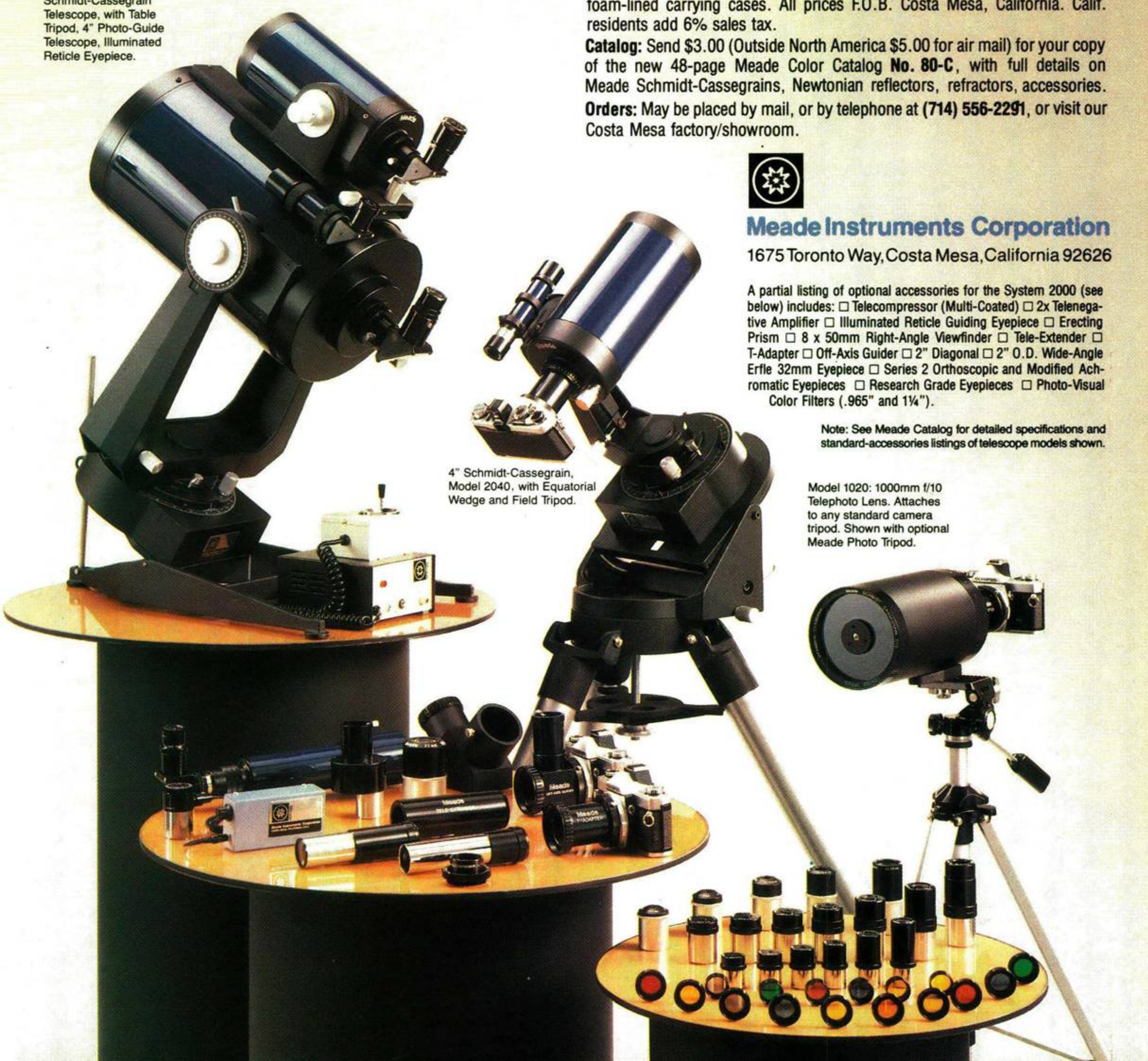
Catalog: Send $3.00 (Outside North America $5.00 for air mail) for your copy of the new 48-page Meade Color Catalog **No. 80-C**, with full details on Meade Schmidt-Cassegrains, Newtonian reflectors, refractors, accessories.

Orders: May be placed by mail, or by telephone at **(714) 556-2291**, or visit our Costa Mesa factory/showroom.

Meade Instruments Corporation
1675 Toronto Way, Costa Mesa, California 92626

A partial listing of optional accessories for the System 2000 (see below) includes: ☐ Telecompressor (Multi-Coated) ☐ 2x Telenegative Amplifier ☐ Illuminated Reticle Guiding Eyepiece ☐ Erecting Prism ☐ 8 x 50mm Right-Angle Viewfinder ☐ Tele-Extender ☐ T-Adapter ☐ Off-Axis Guider ☐ 2" Diagonal ☐ 2" O.D. Wide-Angle Erfle 32mm Eyepiece ☐ Series 2 Orthoscopic and Modified Achromatic Eyepieces ☐ Research Grade Eyepieces ☐ Photo-Visual Color Filters (.965" and 1¼").

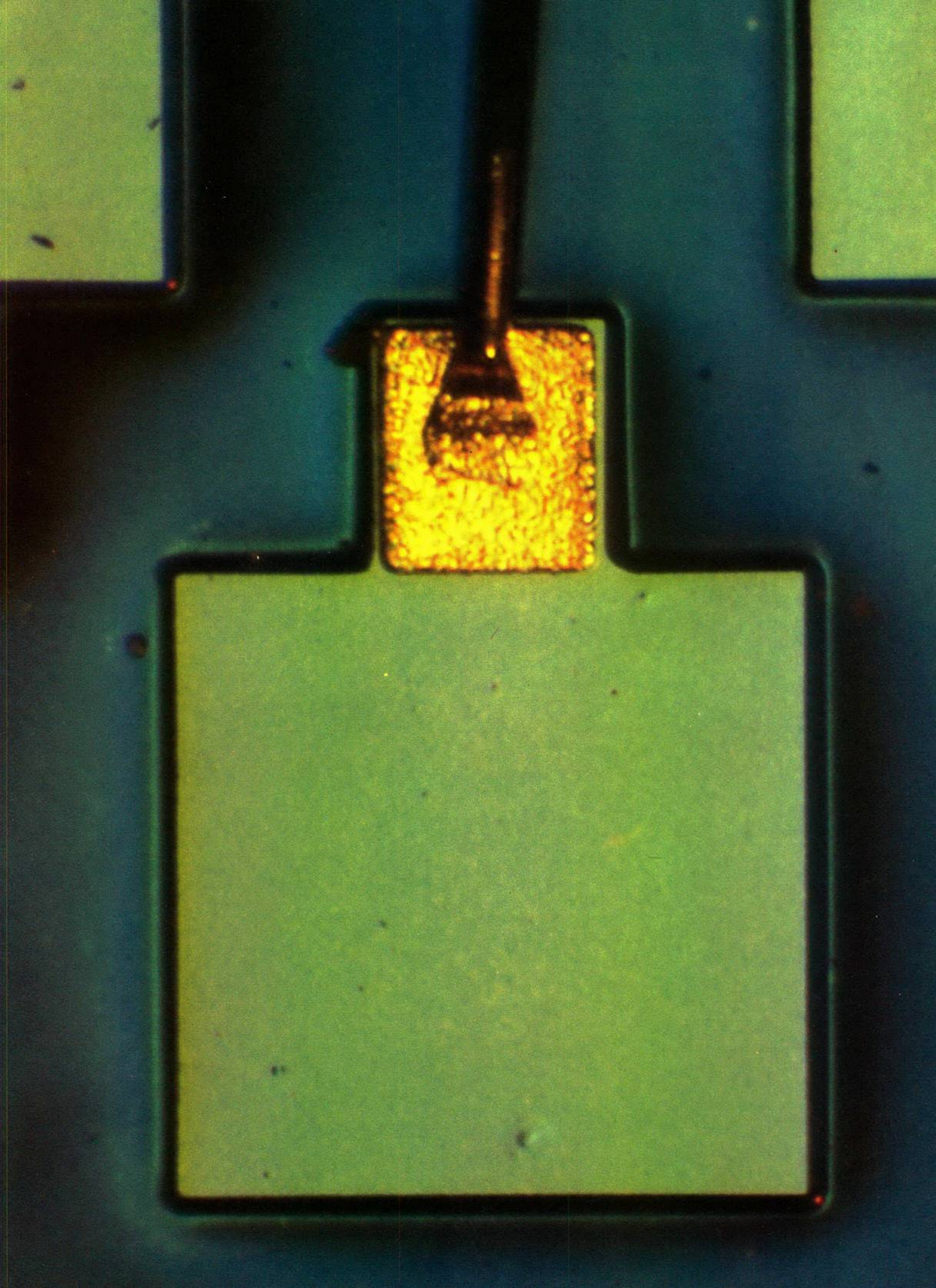
Note: See Meade Catalog for detailed specifications and standard-accessories listings of telescope models shown.



Model 2080: 8" Schmidt-Cassegrain Telescope, with Table Tripod, 4" Photo-Guide Telescope, Illuminated Reticle Eyepiece.

4" Schmidt-Cassegrain, Model 2040, with Equatorial Wedge and Field Tripod.

Model 1020: 1000mm f/10 Telephoto Lens. Attaches to any standard camera tripod. Shown with optional Meade Photo Tripod.



ASTRONOMY

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Cover: On the 12th, the Voyager 1 spacecraft will swing past the planet Saturn and its system of satellites and radio back hundreds of pictures of unprecedented quality. This month, ASTRONOMY explores the fascinating new electronic detectors that are fast replacing photographic plates for astronomers, and takes you, via time machine, back to the beginning of the universe: TIME=0:00. These pages: An indium antimonide detector seen at high magnification. Many detectors are made at once; then a hair-thin gold wire is attached to the best one. Photograph by Patrick Waddell.

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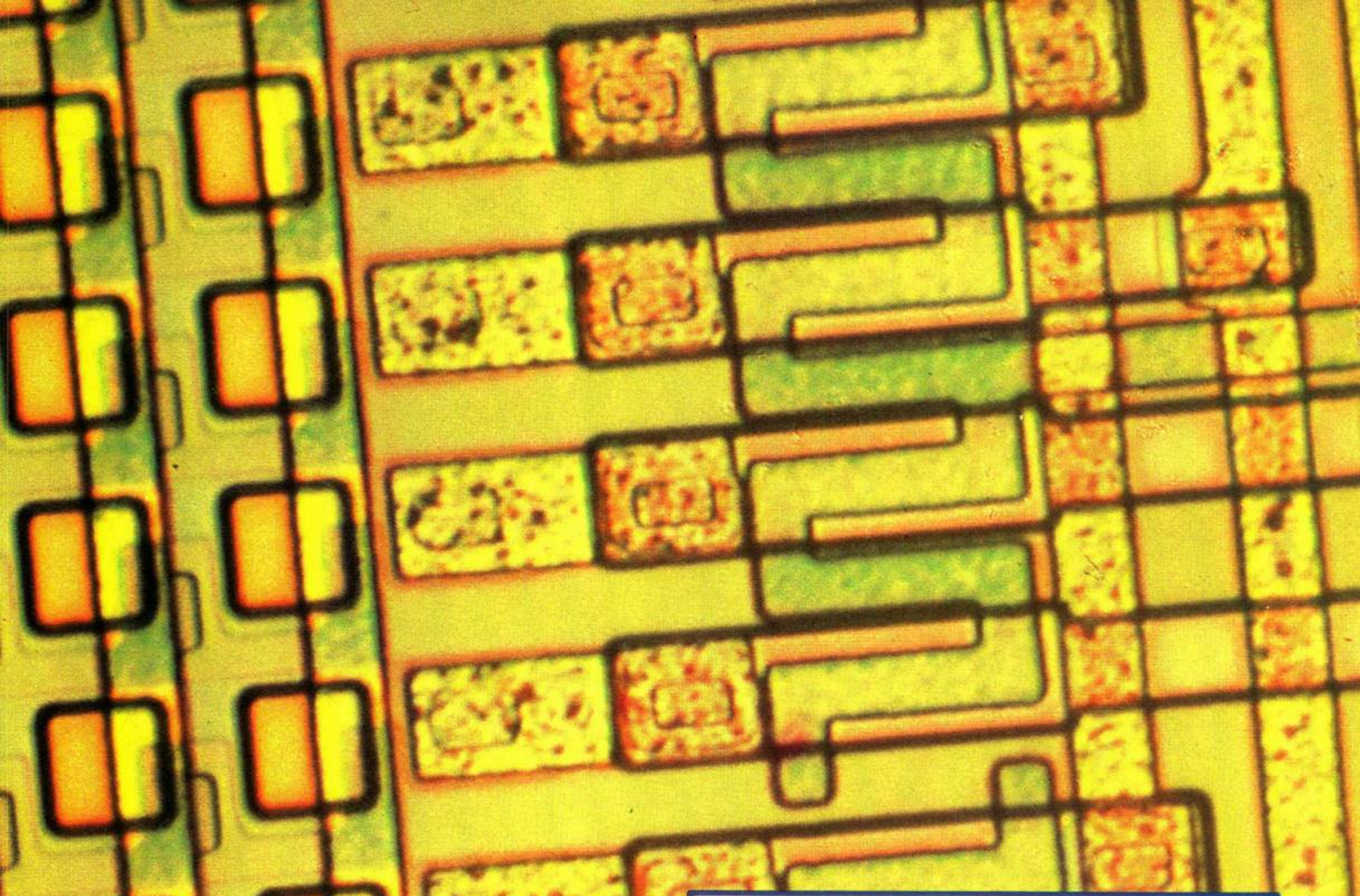
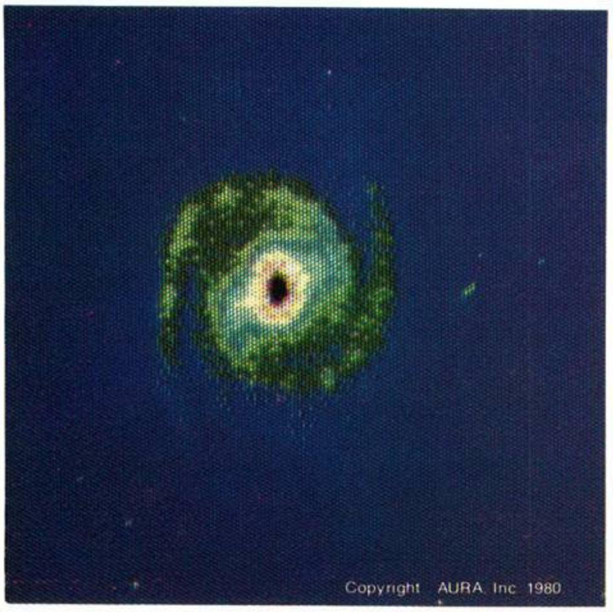


THE IMAGING REVOLUTION

by Michael S. Chabin



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When a physicist wants to study mesons, he can go to an accelerator and smash an atom. Geologists collect rocks, and biologists gather, dissect, stain, and test specimens as a matter of course. Only in astronomy, of all the major branches of science, do the scientists, astronomers, not deal directly with the objects of their study.

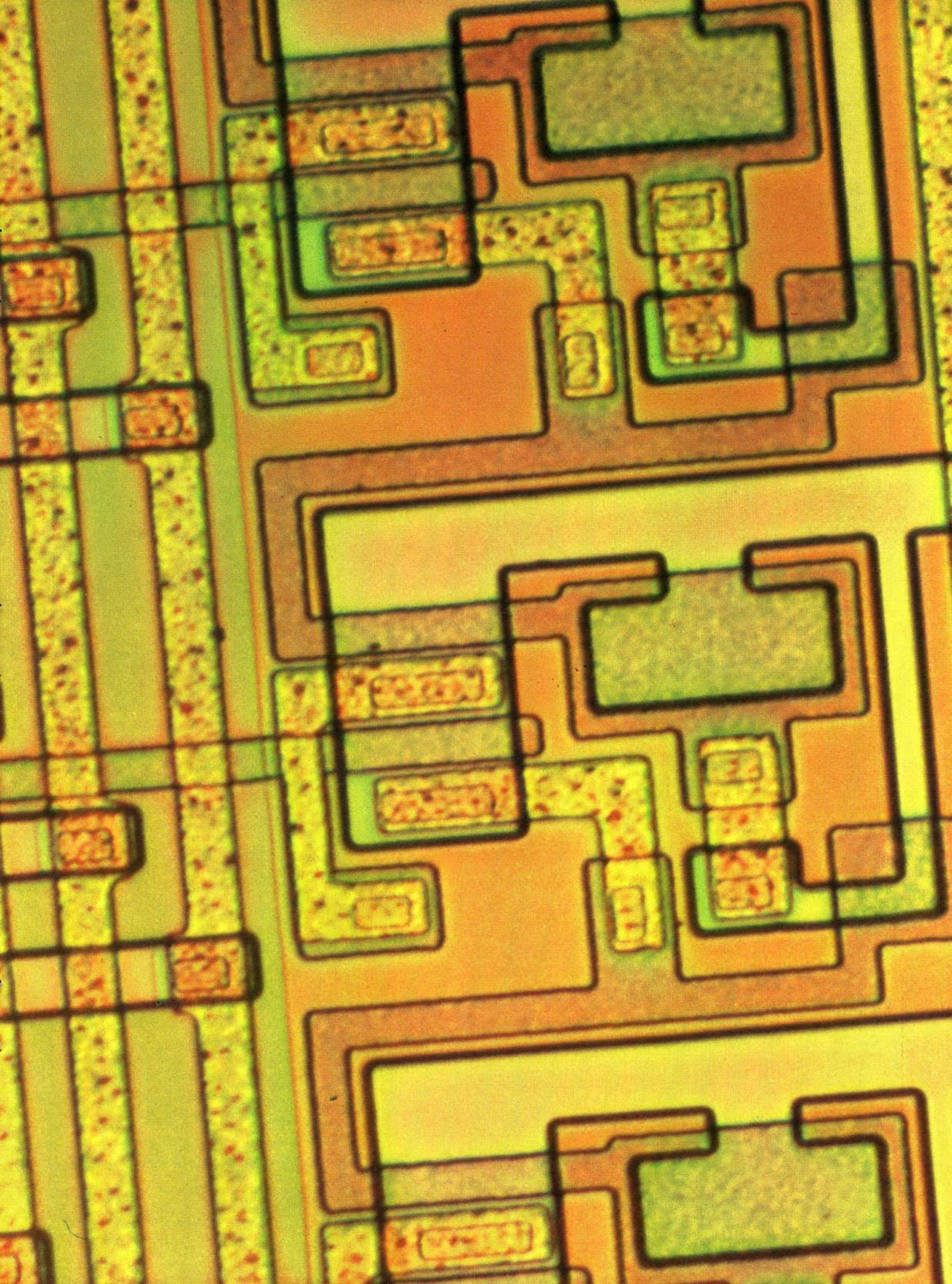
Astronomers deal only with light, or electromagnetic radiation. From radio waves to X-rays, light contains all the information astronomers will ever have about most of the objects in the universe. Fortunately for our present knowledge of the universe, it carries a lot of information.

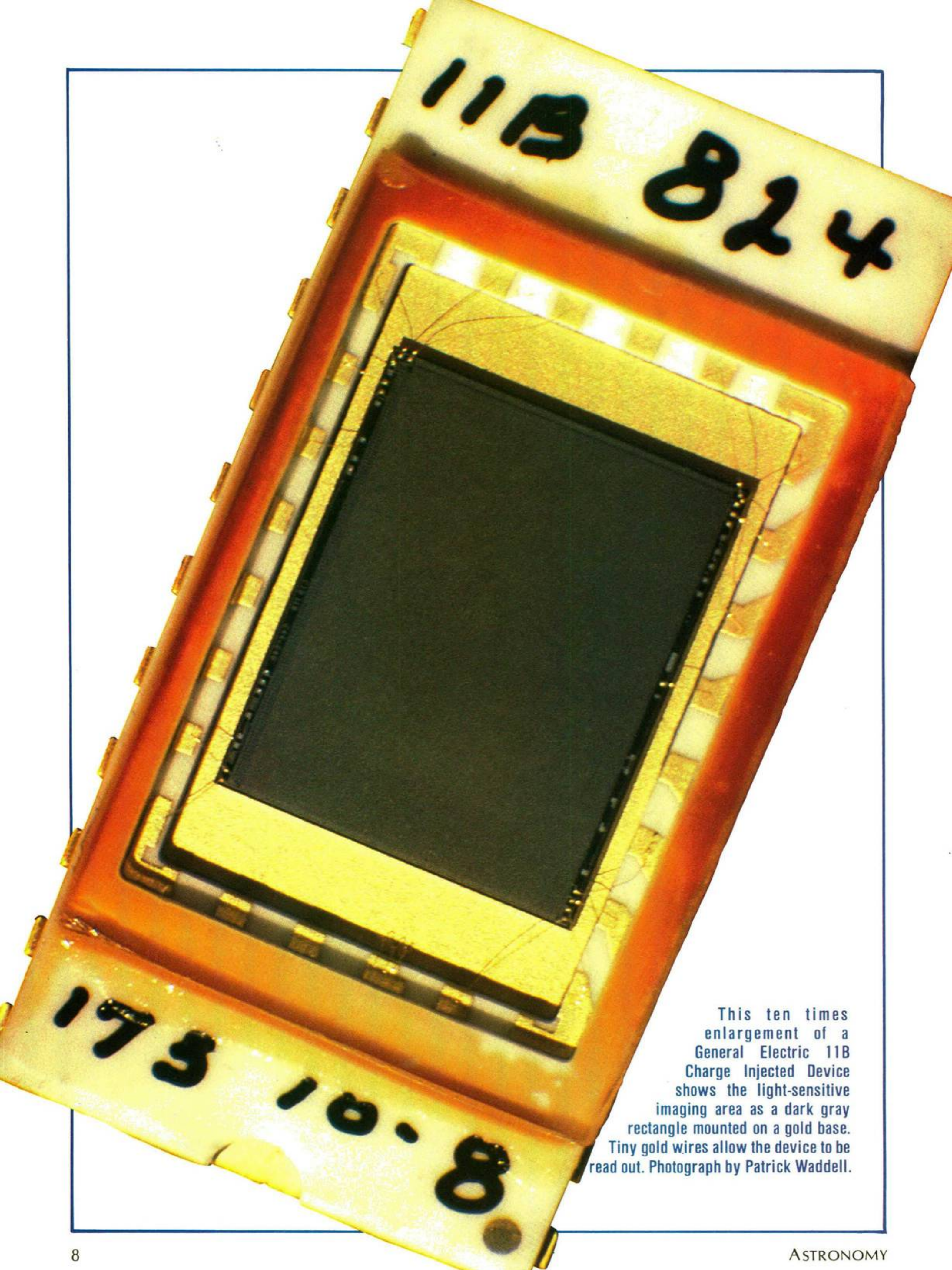
For the bulk of astronomical history, however, scientists have been able to make little use of most of that information. Early observers measured positions of stars and listed them in catalogs. After the invention of the telescope, they measured the positions of stars more accurately and made drawings of nebulae and planets. There are limits to the human eye: what an observer sees can be affected by age, fatigue, and desire. Percival Lowell was only one of several distinguished observers to sketch the canals of Mars.

What was needed, all along, was an objective way to measure starlight.

About 150 years ago, one was discovered: photography. Ranking with the telescope in its importance to astronomy, it allows astronomers to gather, or "integrate," images for many hours, to record spectra too faint to see, and to measure, with reasonable accuracy, the brightnesses of stars and other astronomical objects.

More than any other development, photography has ushered in the modern era of astronomy. But





This ten times enlargement of a General Electric 11B Charge Injected Device shows the light-sensitive imaging area as a dark gray rectangle mounted on a gold base. Tiny gold wires allow the device to be read out. Photograph by Patrick Waddell.

even so basic a tool as photography could not dominate astronomy forever. There are other ways to record and measure light, and the boom in microelectronics has produced new detectors that are, at last, beginning to undermine the pre-eminence of the photographic plate.

The new generation of detectors is growing rapidly. They range from simple devices to instruments so complicated that computers are required to read them. Although photographic plates are still the most widely used detector, electronic devices are receiving unprecedented attention. It seems clear that the great discoveries of the 21st century will be made electronically and recorded in a computer.

Infrared Detectors

Bolometers, among the first of the solid-state detectors to be used, were developed because photographic plates respond little or not at all to infrared light. A bolometer is a piece of material whose resistance to electric current varies with its temperature. It is mounted on a copper plate and cooled to very low temperatures by placing it in a vacuum bottle filled with a liquified gas. (Such a bottle is called a *cryogenic dewar flask.*) Usually the best signals from the detector are obtained at the lowest temperatures: it is common for bolometers to operate in liquid helium at 3 Kelvins.

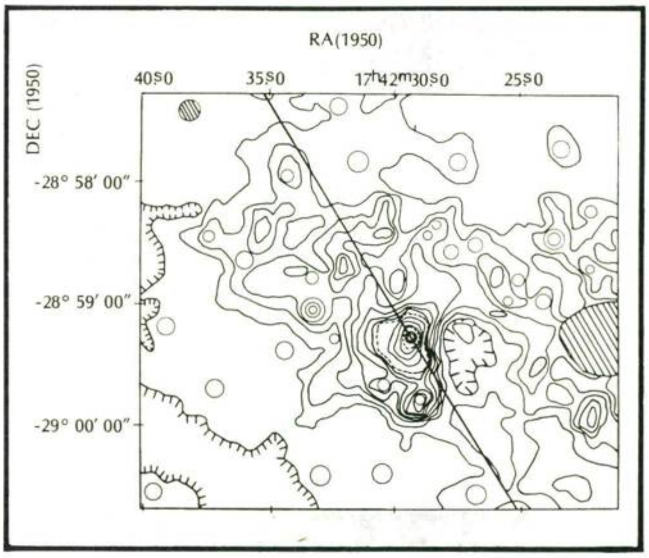
To make an observation, the bolometer is exposed to starlight through a small window in the side of the dewar. Almost everything radiates in the infrared so the signal from the star, the sky background, and even the secondary assembly of the telescope all combine to raise the temperature of the bolometer and change its resistance slightly. That change is measured carefully and recorded.

The astronomer then moves the telescope slightly so that it is no longer pointed directly at the star. Again the signal is measured carefully. The second measurement contains the signal from the empty sky, the secondary assembly, and everything else that might have polluted the first observation. When the second measurement is subtracted from the first, the difference should be a measurement of the star itself with no background at all.

Unfortunately, it doesn't always work that way. Moths, for example, emit a remarkable amount of energy at the infrared wavelength of ten microns. Many observations have been ruined when one flew in front of the telescope or took a walk on the mirror.

What are infrared observations used for? The longer wavelength of infrared light makes it less likely to be intercepted and absorbed by the dust between stars and distributed throughout spiral galaxies. The core of the Milky Way, for example, can be studied at many different infrared wavelengths to yield new information, as can new-born stars still wrapped in cocoons of dust and gas that visible light cannot penetrate. Recently, in an effort to avoid the effects of dust in spirals that obscure their true brightnesses, a team of astronomers measured the infrared luminosities of galaxies with a bolometer to calibrate the Hubble factor.

At wavelengths from five to 20 microns, bolometers are at their best, and they are serviceable up to 1000 microns, or a millimeter wavelength. At shorter wavelengths, however, other detectors are more efficient. One of the most popular for the one to five micron range is a semiconductor called *indium antimonide*. When indium antimonide absorbs a photon, it develops a charge which can be measured accurately. The detector consists of a sapphire wafer mounted upon a tiny piece of gold. On the surface of the sapphire is a row of microscopic deposits of indium antimonide. After testing each of the deposits for its response to light, a gold wire is attached to the best one of them. This detector, once ready for observing, is placed in a dewar like those used for bolometers. For most applications, the high efficiency of indium antimonide makes it unnecessary to cool it beyond the temperature of liquid nitrogen (77 Kelvins).



A 2-micron map of infrared sources, dust, and molecular clouds at the center of our Galaxy with an InSb detector. Courtesy Dr. M. J. Lebofsky.

When astronomer Marcia Lebofsky decided to study the distribution of the dust and measure the position of the large molecular clouds that lie in front of the galactic center, she chose a wavelength of two microns and a detector made of indium antimonide. Using the University of Arizona's 61-inch telescope, she mapped a part of the Galaxy optical astronomers have never been able to study. She located the sources at the center of the Galaxy, mapped the molecular clouds nearby, and demonstrated that the concentration of dust varies significantly in the area.

All of her work would have been impossible at optical wavelengths. Virtually none of the light in the optical part of the spectrum escapes the center of the Galaxy. But equally important is the fact that the work she did was impossible before the development of solid-state detectors that could be used in the infrared.

Solid-State Spectroscopists

Infrared astronomers are not the only ones to benefit from the technology of solid-state detectors. Scientists who work with the optical part of the spectrum have at least as much to gain from the new technology. Among the most powerful tools astronomers have is spectroscopy. Every major observatory has a spectrograph. Some of them have been in use since the last century, while others are computer-controlled and designed for maximum efficiency so that not a single photon is wasted. Until recently, however, *all* of them have had a place for a plateholder at the back. With the spectrograph, scientists learned enormous amounts about the composition of the nearby stars and galaxies. Photographic spectra were perfectly adequate.

Now, using large modern telescopes, astronomers studying the faint stars and galaxies in more detail have run into trouble. Depending upon the observing site, the brightness of the sky at night is from about 21 to 23 magnitudes per square second of arc. At such sites, integrating a spectrum of a 23 magnitude star upon a photographic plate is useless because the sky itself is brighter than the star. The light of the sky overpowers the stellar spectrum. Unfortunately, many of the most interesting, distant, and exotic objects aren't much brighter than the sky. The faint galaxies that seem to surround some, and perhaps all, quasars are only one example.

Recently, however, astronomers who study faint objects were given an enormous help with the development of a small device called a *Reticon*. Reticons are semiconductor detectors similar to indium antimonide detectors. Like the infrared device, it works because light striking it alters the charge on its surface, and that change can be measured precisely. But it is different from the infrared detector because it is useful over most of the spectrum of visible light, and more importantly, because it is not really a single detector at all.

A Reticon consists of two rows of up to 512 microscopic detectors. It is mounted at the back of the spectrograph in place of the photographic plate. At the front of the spectrograph is a mask with two tiny holes drilled in it. The mask is arranged so that when starlight goes down one of the holes, its spectrum falls on one of the Reticon's two rows of detectors. While the first row of detectors measures the spectrum of the star, the second measures the light from the empty sky. Every few minutes the telescope is moved so that both rows of detectors spend equal amounts of time measuring the star and the sky.

The result is two sets of measurements: one set of starlight plus skylight, and the other set of skylight alone. When the sky measurements are subtracted from the star-plus-sky measurements, the result should be a nearly perfect spectrum of the star — almost as if it had been taken through a vacuum.

Even when a star or galaxy is only 1/10 as bright as the sky background, its signal can reliably be extracted from the overwhelming light of the sky. Even though sky subtraction has not made it possible to observe as if there were no sky at all, it certainly has made it possible for astronomers to routinely observe stars significantly fainter than the sky itself.

Solid-State "Magic"

Why does it work? If it weren't for the extremely accurate performance of the detectors in the Reticon array, it wouldn't. Although photographic plates are made with incredible precision and under the most rigorously controlled environments, there is no way to guarantee the response of a specific area on a specific plate. Each is unique and once it has been exposed, it can't be used again. But the individual detectors of a Reticon can be used thousands of times, and calibrated until its characteristics are very well known.

Photographic plates are not only detectors, but a storage device as well. When observing with a solid-state detector, it is necessary to use a computer for storage. Although it's more complicated, that leads to another advantage electronic detectors have over photographic plates. When observing with a Reticon, the astronomer will often use exposure times (or "integrations") of about five minutes. At the end of each integration, he can take a quick look at the spectrum and continue. Since the individual five-minute integrations are usually stored in computer memory as independent files to be added later, all the original data are saved. Sometimes, especially when the star is variable, the astronomer can choose which files to add together and which not to.

AM Herculis is a cataclysmic variable star with a period of a little over three hours. During that time, its spectrum changes radically. That is why when astronomer Bob Williams decided to study AM Herculis, he chose to use a Reticon. By observing in small increments of time, he was able to study subtle changes in the spectrum only a few minutes apart without sacrificing the ability to add 30 minutes together for careful study of a faint spectral line.

Pictures, Too!

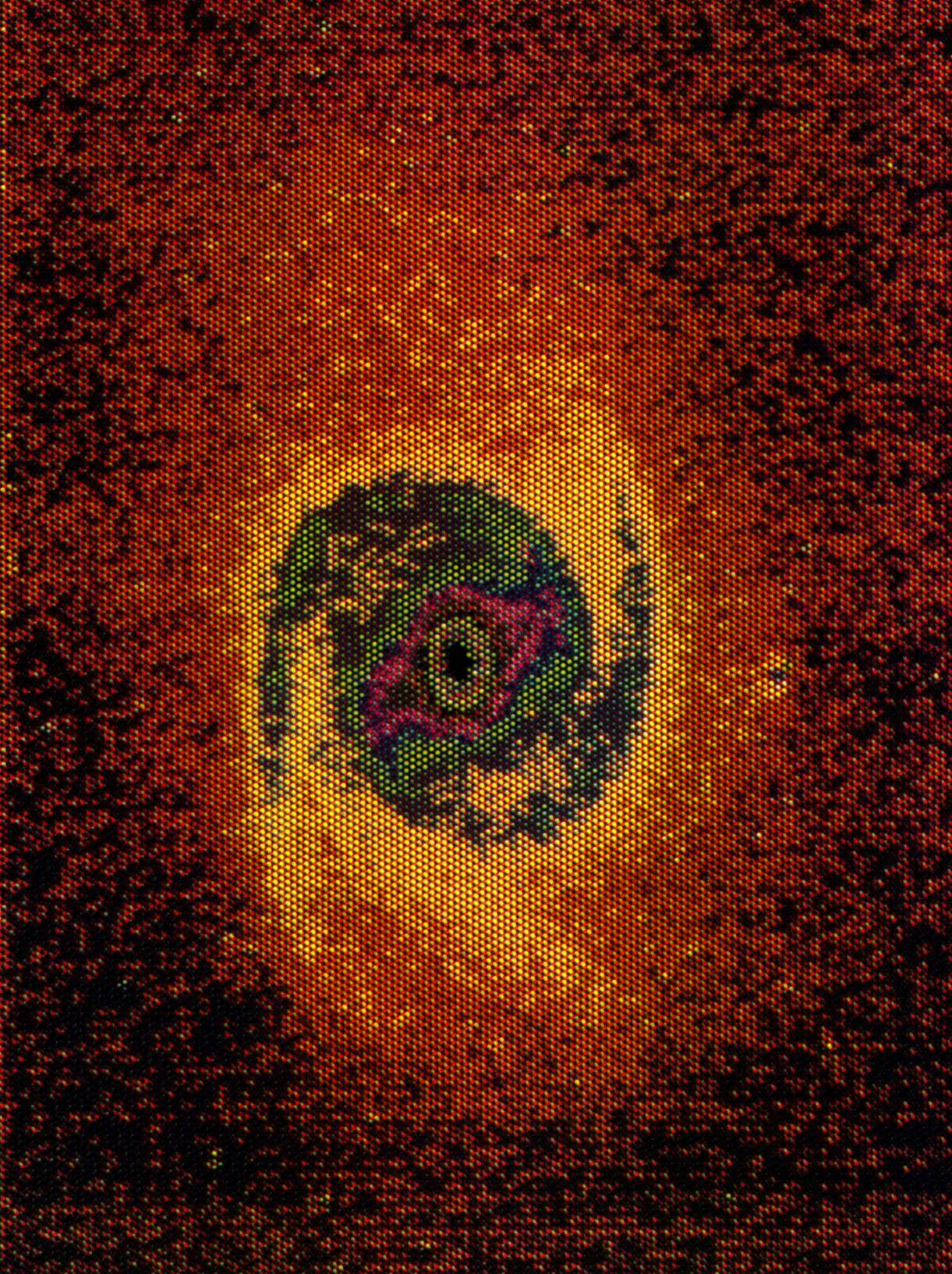
Whether used individually, as in the indium antimonide detector, or in arrays as in the Reticon, solid-state detectors promise to contribute a great deal more to astronomy. One of the best parts of astronomy has always been the pictures it provides. For that reason, some of the most exciting of the new generation of detectors are two-dimensional. Called Charge Injected Devices (CIDs) or Charge Coupled Devices (CCDs) depending upon how they operate and how the measurements are read out from them, they are basically solid-state, semiconductor detectors set in tiny arrays up to 512 detectors on a side.

Many of the largest and most influential observatories in the country are working on two-dimensional solid-state detectors and some are already using them. A CID, for example, provides the high-speed feedback necessary to operate the active optics at the Multiple Mirror Telescope.

There are a variety of reasons for those observatories to be excited about semiconductor detectors. Among the most important of them is a measure of detectors called "quantum efficiency." For every 1,000 photons that fall upon a photographic plate, between five and 30 are recorded. (The rest are turned into heat or are reflected.) It is theoretically possible for a cooled CCD to record as many as 800 of them. When this happens, the quantum efficiency is said to be 80%. Even though they don't actually reach such a high efficiency, it is common for them to work in the 20% to 50% range.

The efficiency of the new detectors would be enough by itself to fuel the enthusiasm of

After a one-minute exposure at the focus of the Kitt Peak 4-meter telescope, this Fairchild 211 CCD image of a barred spiral galaxy (displayed in false color) shows the faint structure in the outer arms as well as structure right into the bright core. Other displays of the same data are shown on pages 6 and 13. A photographic plate would have required one hour of exposure.



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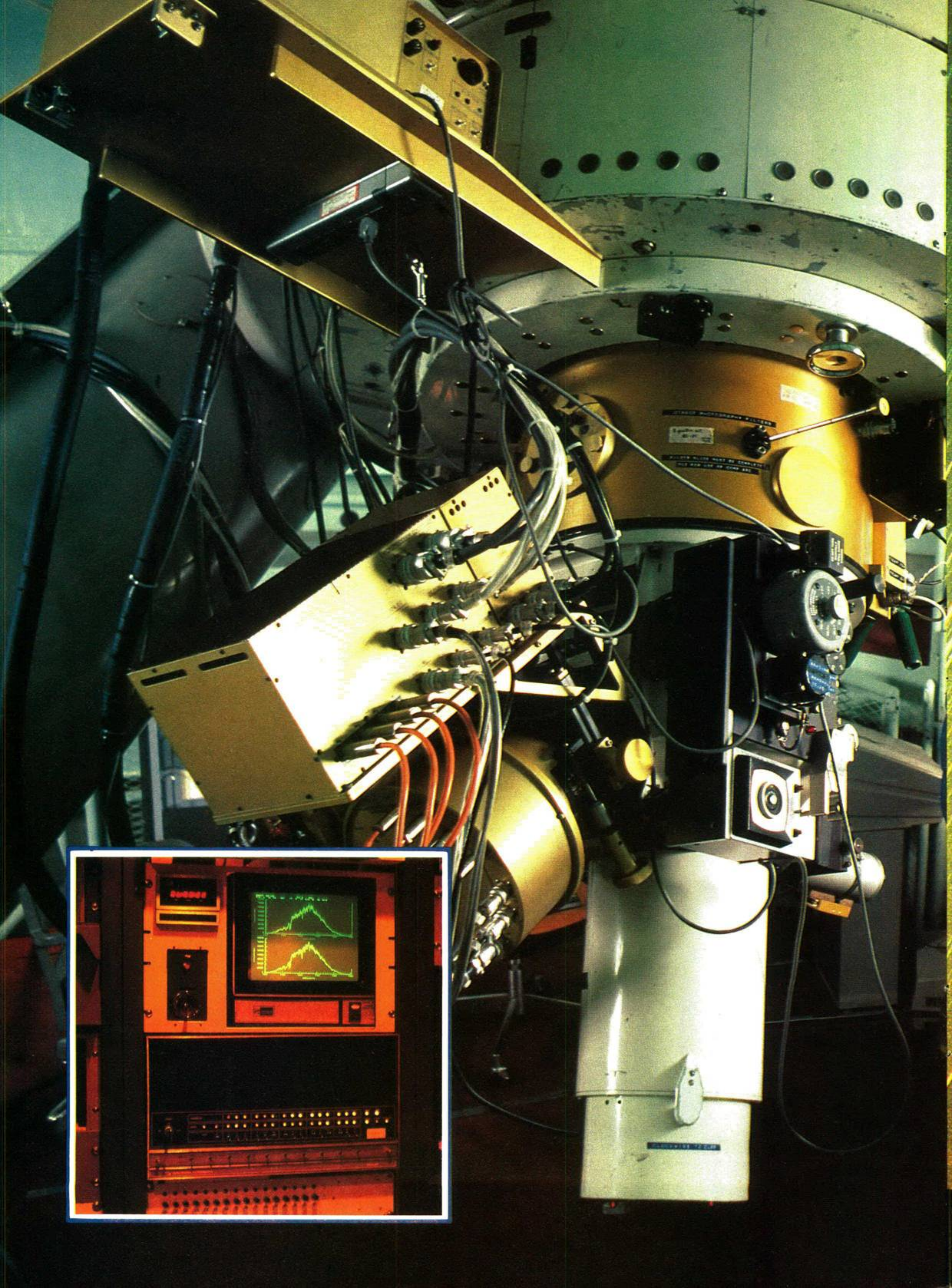

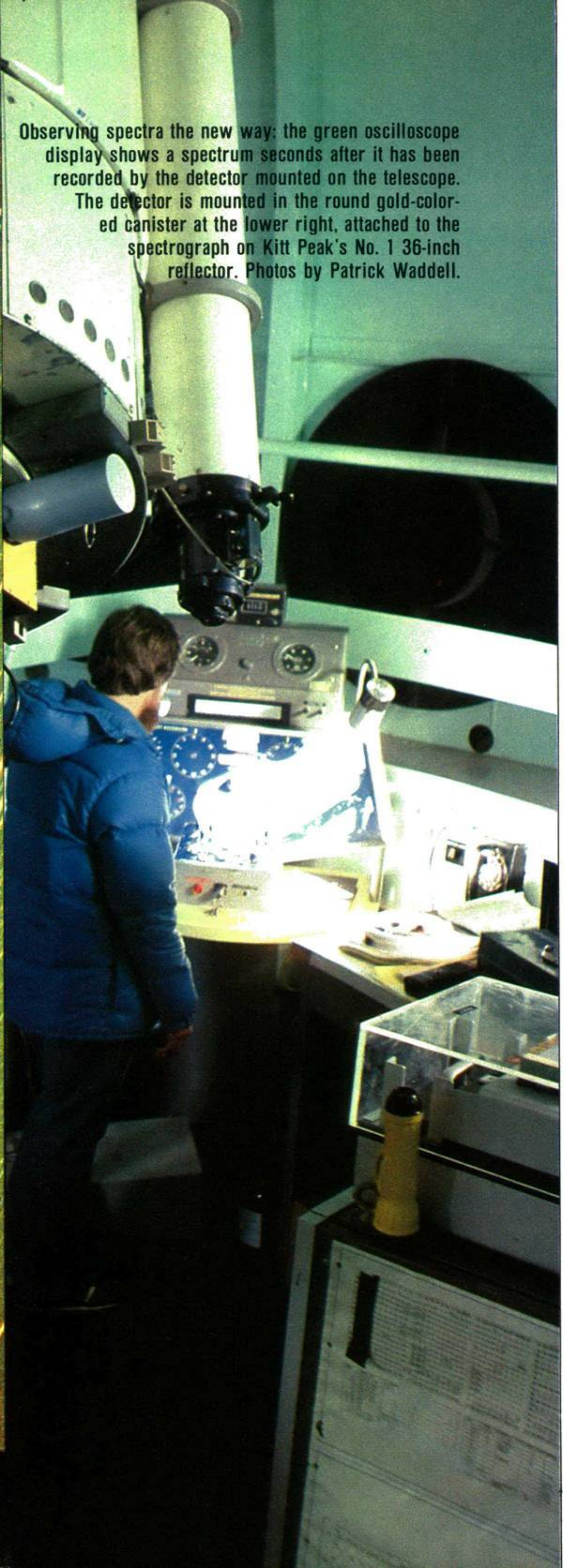

Observing spectra the new way: the green oscilloscope display shows a spectrum seconds after it has been recorded by the detector mounted on the telescope. The detector is mounted in the round gold-colored canister at the lower right, attached to the spectrograph on Kitt Peak's No. 1 36-inch reflector. Photos by Patrick Waddell.

astronomers, but there is much more. For example, if a CCD has 500 detectors on each of its four sides, it contains a quarter of a million microscopic photometers each capable of extremely accurate measurements of light over most of the spectrum. For measuring the brightness of objects such as galaxies, the implications are obvious. Some astronomers are already putting polarizing filters in front of them to map the polarization of light in galaxies and dust clouds.

Another advantage of solid-state devices is their "dyanamic range," or their ability to function over a wide range of brightness. This was demonstrated for CCDs recently at the National Observatory's 4-meter telescope on Kitt Peak. Astronomer Garth Illingworth took a one-minute integration of a barred spiral galaxy through a deep red filter. When the data were reduced, he was able to measure the faint outer structure of the spiral arms, the large HII regions of active star formation in the arms themselves and, to some extent, the structure of the hot core and bar at the center of the galaxy.

If he had attempted to get the same information photographically, it would have required an hour-long exposure. The central part of the galaxy would have been too overexposed to have been useful, and to obtain the brightness of different spots in the galaxy would have required complex (and inaccurate) calibrations.

The list of new astronomical uses for the new detectors is growing continuously. Some of them will ride on the Galileo mission to Jupiter as the TV cameras. Others are designed to work aboard the Space Telescope to detect light from the farthest corners of the universe. The rest will remain on Earth to extend the usefulness of ground-based telescopes. But all of them promise to keep observational astronomy exciting for years to come.

Michael Chabin, in addition to free-lance writing, operates the University of Arizona's 2.3-meter telescope on Kitt Peak.

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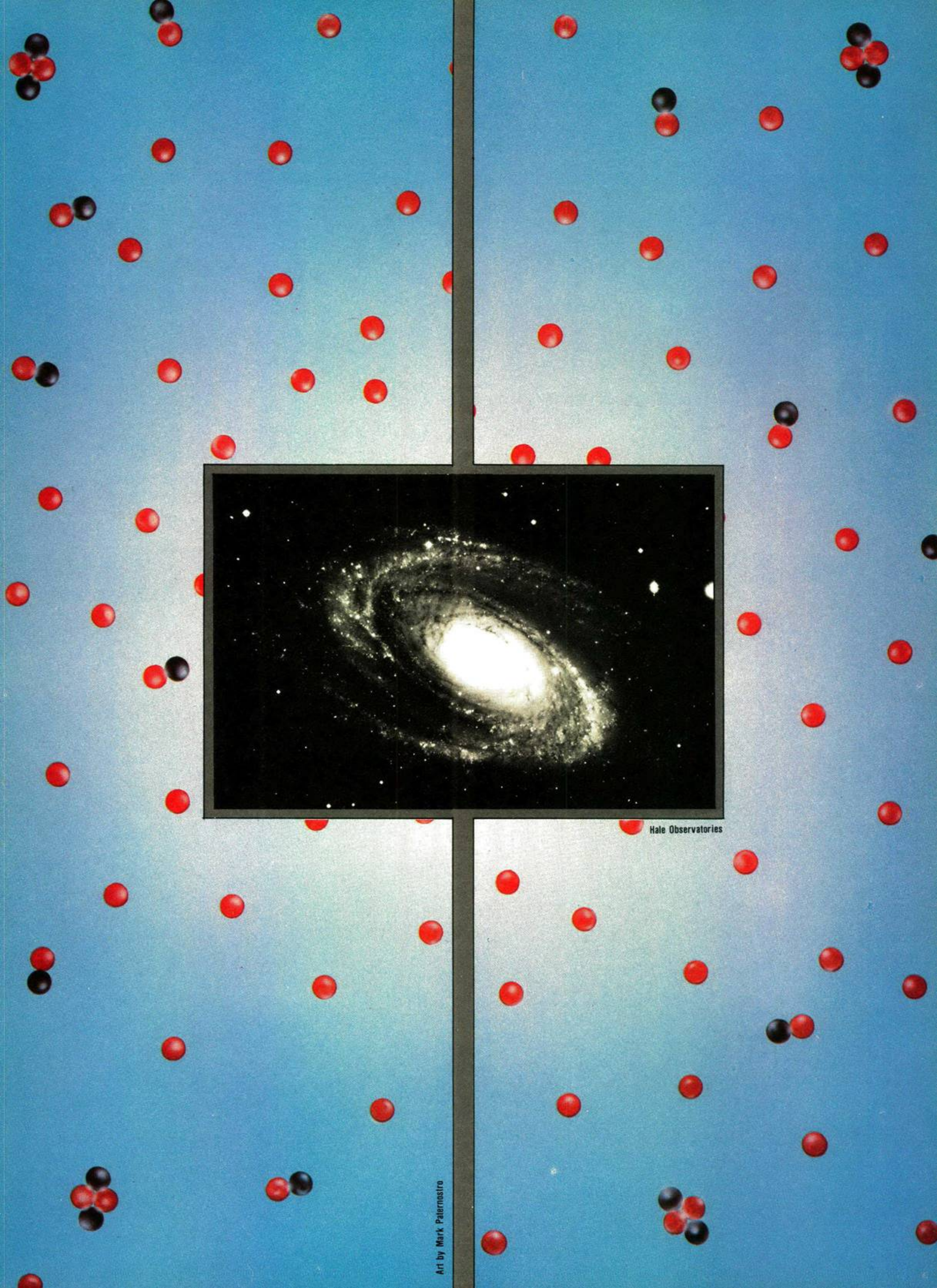


Hale Observatories

Art by Mark Paternostro

universe 0:00

by David Darling

A journey awaits us — to Time Zero. We'll travel back, far back, through time and space to when the universe was new: a journey to the genesis of our universe across a time gulf of some fifteen thousand million years.

Climb aboard an imaginary time machine. First we'll take a quick hop back to the late 1920s. Here we find a period of major upheaval in science. An earthquake is ripping through the heart of astronomy, its epicenter the fantastic concept of a violently expanding universe.

But to feel the first tremors of that earthquake, we must go back further — to the year 1916. It was then that General Relativity burst onto the scientific scene, changing our whole conception of the way the universe is put together. Albert Einstein's genius had created a totally new theory of gravitation...

Gravity and the Expanding Universe

Let's get that achievement in perspective. On a cosmic scale, gravity is the master force. When we talk about interactions between galaxies, or between stars, or even between planets, these are gravitational interactions. Of the so-called "four fundamental forces," gravitation, electromagnetism, and the strong and weak nuclear forces, gravitation dominates over large distances.

Over very small distances, like those you find within atoms, or the nuclei of atoms, gravity fades into total insignificance. In the strange world of the atom and subatomic particles electromagnetism and the less familiar nuclear forces take on the major roles.

Let's start with gravitation, though, for the moment. This is the force that molded galaxies in the early universe, that sucks star matter down the abyss of a black hole, and that controls the ultimate fate of the cosmos. And if gravity is the key to the universe, General Relativity in turn seems to be the key to gravity.

We're traveling back to the first hour of the universe. But how can we say that the universe ever had a first hour? Maybe it's always been pretty much the same as we see it today. Maybe we live in a "steady state" universe.

The equations of Einstein's great theory are very subtle. They have solutions — highly significant ones — but you have to look hard for them. Einstein himself spent two years seeking a solution to his equations for the universe as a whole. Working independently, the physicist Willem de Sitter did similar research and published his results in 1917, about the same time as Einstein.

Their conclusion was astonishing. If the General Theory of Relativity holds true, it turns out that the entire universe must be either expanding or contracting. There are simply no solutions of the equations which allow for an unchanging cosmos. Einstein even introduced changes in the equations in his attempt to find a static cosmological model — and failed. The so-called Einstein universe was unstable.

By 1922, the early theoretical work had been completed. The mathematician Alexander Friedmann, working from the original unmodified field equations, gave us the expanding universe models of modern cosmology.

And soon the models were to become the reality. Almost before the print had dried on the papers of the theorists, astonishing support for the new cosmology sprang from the photographic plates of the observers. The galaxies were racing away from us.

Spearheading the observational attack was Edwin Hubble. His intense study of the spectra of distant galaxies brought us face to face with the concept of an expanding universe. *Redshift, velocity of recession,* and *Hubble's Law* became buzzwords of contemporary astronomy, with the discovery that the galaxies fly apart with a speed in direct proportion to their separation distance.

Now the real journey begins. As we re-enter our time capsule, consider this: An expanding universe must also be an evolving universe. In the distant past, the galaxies were not as they are today. They were much closer together, and they were younger, brighter, more energetic. The universe itself was more compact and more dense. At the moment the expansion began in a colossal explosion astronomers call the Big Bang, the universe was an unimaginably hostile place. It's to that initial instant of time and the few minutes following it that we now return.

Journey to Genesis

We travel fast. The clock's hands spin back: 1 billion, 2 billion, 3 billion years. On Earth, the most primitive of life-forms are struggling on the first rungs of the evolutionary ladder.

At a point 5 billion years ago, we pause. We've reached that time when the infant Sun first powered up its nuclear furnaces, and the planets were still just local condensations in the remnant solar nebula. Looking beyond the Milky Way, we find an unfamiliar universe. Quasars, the energy tycoons of the cosmos, appear to be more numerous and not so far distant. The Galaxies in general are more "active," showing signs of their youth in the brightness of their nuclei and the compactness of their blue-star-dominated spiral arms.

Further back we go, to the dawn of the galactic universe. Now we find it simpler to measure time in terms of years After the Big Bang (A.B.B.). Ten billion years ago becomes about five billion years A.B.B. At around that time, the first recognizable galaxies were taking shape: rotating, condensing blobs of primordial hydrogen leavened with helium. Reaching to two billion years A.B.B., we witness a universe populated only by the astonishing quasars: energy geysers tapping a power source we can barely speculate on.

We stop only briefly to gaze on the two billion-year-old cosmos, our last direct link with the present-day universe, before making the final hop to Time Zero. (Fortunately, our imaginary time capsule can be made to function through the most hostile of environments, including the center of a Big Bang.)

At Time Zero, we ask: How would things appear? What would the universe look like if it were all, matter and space together, concentrated into a region smaller even than the solar system?

We can only guess. Remember, though, that this isn't matter as we normally think of it. Under the unique conditions prevailing at the time of the Big Bang, bizarre physical processes were taking place. Stretching the laws of physics to their very limits we find a cosmos filled by massive hadrons and space-time quanta. We'll return for an in-depth look at these strange beasts later on.

Back to Time Zero. The stage is set for the Big Bang and all of the curious scenes that are to follow in the first hour of the universe. Picture the Big Bang as some highly complex astrophysical play, and we as the audience. Matter, energy, and radiation make up the cast and the laws of physics, the plot. Let's browse through the program before the action starts.

The Laws of Physics

Two major physical theories will control the drama that's about to unfold. General relativity is one, and quantum mechanics the other. Under normal conditions we'd find it hard to visualize how these two very different areas of physics could overlap. They represent the two extremes: the macroscopic and the microscopic viewpoints of the universe. Yet during the first few moments of genesis there was a marriage between them, a few brief instants when the granular (or quantum) nature of space-time was revealed.

We glanced at Einstein's theory earlier, a theory which accounts for gravitational forces in terms of the local curvature of space-time. Now let's go further. Let's enter the world of curved space-time and the quantum, and go to the threshold of our understanding of the physical universe.

What we feel — or measure — as a force of gravity, is simply a manifestation of the local curvature of space-time. A good example is our own solar system. The Sun, apparently exerting some mysterious unseen force on the planets and all other members of its family, really lies deep within a gravitational well — the depression it makes in space-time. Around the inner edge of this well the planets move, like marbles rolling around the sloping sides of a soup bowl.

In general, the more massive something is, the deeper the well it forms in the local region of space-time. Stars make deeper gravitational wells than planets...galaxies make deeper wells than stars...and so on. What's more, the denser a given chunk of matter is, the steeper are the sides of its gravitational well.

To an astronaut on an interplanetary mission or an astrophysicist probing the convolutions of a black hole, mapping small regions of space-time is of great interest. Cosmologists, on the other hand, take a more global view — one which encompasses the whole of the universe. Their key question is: What's the overall structure of space-time?

As spectators of the first hour of the universe, we're also keen to learn that overall structure. But more importantly, we'd like to know how that structure is affected by the staggering densities which existed at the time of the Big Bang.

how do we know?

How can we know what the beginning of the universe was like? Scientists use three different sources of knowledge together to reconstruct the story of genesis. By *observing* distant galaxies and quasars, astronomers peer further and further back in time, learning something about conditions in the universe long ago. *Experimentation* in high-energy physics tells us about the ultimate structure of matter and energy, and how they interact under the extreme conditions at the beginning of time. Finally, *calculation* on the basis of the great theories of modern physics together with data derived from both observation and experimentation, provide an exact description of the evolution of the cosmos from the tiniest fraction of a microsecond after the Big Bang.

Bell Labs photo

Lick Observatory photo

Where was the boundary of space — the shape of the universe — at the instant before the initial explosion occurred? There are just two possibilities. Unfortunately, neither gives us the satisfaction of being able to visualize it. Space, at Time Zero, was either infinitely small — a mere point without dimensions — or infinitely large.

In the language of General Relativity, space has either a positive or negative curvature. Positive curvature, like that of a sphere, leads to a universe with a finite volume. If today's universe is positively curved, then even though it's expanding, it will always have a finite size. Negative curvature is a little more tricky. It involves space that extends forever without folding back on itself — infinite space.

In principle, it's easy to find out what type of curvature the universe has. The method is based on a concept we mentioned earlier, that the geometry of space-time is controlled by the distribution of matter. To discover how space is curved, just measure the average density of matter in the universe and make the test. Above a certain known critical density, there's enough mass around to pull space back on itself, producing a positive curvature and a finite volume. Below that same "magic" density, space must extend forever and the universe be infinite.

There's one small problem. Finding out the average density of matter in the universe is an enormously complex affair. How much invisible gas is swimming the intergalactic voids? How much dead star stuff lies within the bottomless pits of black holes? How much other hidden matter lurks throughout space? Estimates vary and we're still very unsure.

Whatever the outcome of this crucial test, though, one thing's clear. The curvature of space today is the same as it was at the time of the Big Bang. Infinite universes stay infinite; finite universes stay finite.

Taking first the case of a positively curved space, let's look again at the situation right at the Big Bang. Right away, our earlier question on what the explosion scene might have looked like becomes meaningless. At the time of the Big Bang there would have been no vantage point from which to see the event. There was no "outside." The primeval atom, the genesis egg from which the universe was to evolve, would itself have occupied the whole of space. The tiny, embryonic cosmos was so highly curved that it closed in on itself, containing at all points the very matter and energy which warped it.

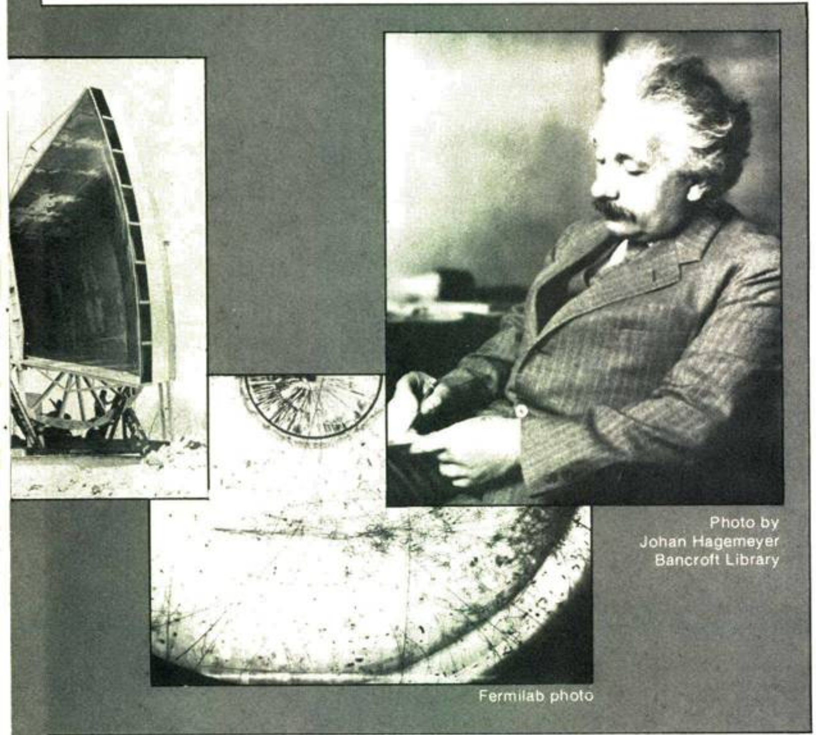


Photo by
Johan Hagemeyer
Bancroft Library

Fermilab photo

And even today the situation is unchanged. We still live within a stupendous explosion, the shape of which is defined by the distribution of matter within it. There is no such thing as an outside.

Will the universe ever stop expanding? If space is finite, yes. Not only will the expansion finally stop, it'll be followed by a long period of contraction until all the matter is once again squeezed into a fantastically small space at ultra-high density. Maybe this would then mark the beginning for a new phase of expansion, just one more cycle in a never-ending series of oscillations, but this is beyond the knowledge of present physics.

Matter in an infinite universe, though, behaves differently. From the moment it starts its headlong expansion within an already infinite space, it's doomed to expand forever. There can only be one Big Bang in a universe of negative curvature.

The Origin of the Elements

The curtains have drawn back and the players are on stage. We glance at the chronometer and see that one second has already passed since the start of the Big Bang.

One second — surely we couldn't have missed much in so short a period. Maybe a slight cooling and thinning out of the pre-explosion material?

No. We missed virtually every significant event in the early development of the universe! Incredibly, during that very first second of genesis, the debris thrown out by the Big Bang — the material in the universe — underwent several crucial transformations. This was the Golden Age of ultrafast phenomena.

During the first second of the universe, all the stable building blocks of atomic nuclei formed. At Time Zero + One Second, our capsule is surrounded by a hot melange of familiar subatomic particles. Protons and neutrons, the basic components of all nuclei, emerged from an earlier micro-era, alongside electrons, positrons, photons, and the phantom neutrinos and antineutrinos.

Let's emphasize that at one second A.B.B., this small group of particles was all the universe contained. From this super-hot stew, all of the nuclei, atoms, and ultimately the stars and galaxies of the matured universe would form.

Two ingredients of our stew are neutrons and protons. Are the components of normal atomic nuclei already forming, then, at this early stage? No. Even powerfully bonded nuclei instantly blow apart at 10 billion degree temperatures. Nothing more complex than hydrogen nuclei — single protons — could survive the searing climate of the one-second-old cosmos.

Now consider something else: present-day element abundances. Carbon, maybe? Silicon? Oxygen? Let your mind wander away from Earth, to the stars and to the universe at large. Which elements are so common that they're totally dominant throughout all of space?

There are only two: the lightest elements, hydrogen and helium. On average, of every 100 atomic nuclei in the universe, about 75 are hydrogen and about 25 helium. Elements heavier than helium would struggle to contribute even 1 to that total.

Let's focus in on those two key elements. Today, nuclei of hydrogen outnumber those of helium by around 3-to-1 — a pretty healthy margin in favor of the lighter element, it seems. But remember what's happening at the cores of all normal, stable stars throughout the universe. Hydrogen is being converted into helium. Over the last 15 billion years or so, since thermonuclear reactions began at the centers of the first stars, the cosmic balance of power has shifted. It has slid inexorably away from hydrogen, and toward its chief fusion product, helium.

Our best estimates point to an original hydrogen-to-helium ratio of about 9-to-1. But without star cores to burn hydrogen "fuel" to helium "ashes," we arrive at an interesting question. Exactly when was the primitive helium formed? Certainly not at the 1 second A.B.B. stage, with its nucleus-tearing temperatures. Let's watch the scene closely, as the cosmic explosion moves on from the one second mark. Can we pinpoint the moment of creation of the first helium?

Fifteen seconds A.B.B. The temperature has fallen to a modest three billion K and it's cool enough for some stable nuclei like helium-4 (He^4), the normal form of helium, to exist. So where is the helium? We can find no trace of it.

Think of how a helium nucleus is made up: four particles in all — 2 protons and 2 neutrons — bonded together by strong nuclear forces. How would such a nucleus be manufactured in the quarter-minute old, fast-expanding cosmos? Answer: on an assembly-line of fast collisions involving just 2 particles at at time.

Starting with individual neutrons and protons there are several ways you can make a helium nucleus. A neutron and a proton will combine to give a nucleus of deuterium (heavy hydrogen). A further collision between deuterium and a neutron produces tritium, H^3, the top-weight form of hydrogen. Taking another path, the deuterium might slam into a proton and emerge as helium-3 (He^3). Either way, helium-4 is just one short step away. Tritium swallows a proton and becomes helium-4; helium-3 swallows a neutron and does the same. Yet fifteen seconds following the Big Bang, there's no stable nucleus in the universe except hydrogen. Why?

The answer lies with the temperature stability of the middle-men: deuterium, tritium and helium-3 — especially deuterium. Three billion degrees is still too high for these weaker bound nuclei, and they simply blow apart the instant they form. Although the end product, helium-4, is stable at much higher temperatures, its formation is held up by the less stable nature of the intermediate nuclei.

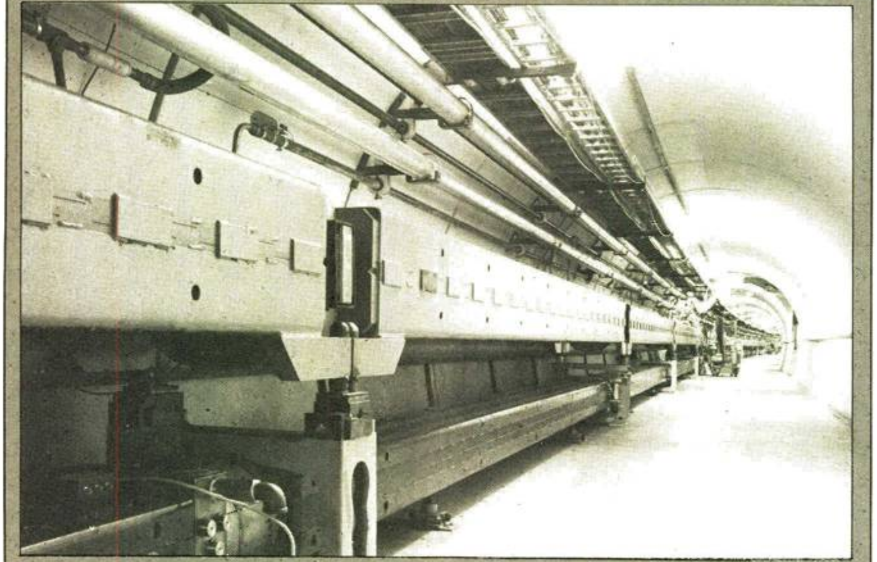
One hundred seconds following the Big Bang, small quantities of helium-4 start to appear. The temperature is *sliding down* to a billion degrees, and tritium and helium-3 are starting to cling together long enough for the final jump to helium-4 to occur.

Just below the one billion degree barrier it happens. Suddenly the universe is 10% helium, and we're through the dramatic moment when deuterium finally achieves stability. With the chain reaction process from neutrons and protons to helium-4 no longer choked off at the second level (deuterium), virtually all the remaining free neutrons are swallowed up into helium nuclei.

Our time capsule hovers in the 200-second-old universe, sensors scanning its surroundings. Blindingly intense radiation bathes every corner of space. Photons swarm over the cosmos: a billion such bundles of electromagnetic radiation for every proton and neutron. Electrons and their antiparticles, the positrons, diminish in number as they totally annihilate each other upon collision.

Nearly 4 minutes have passed since the initial explosion. The universe contains roughly equal numbers of electrons and protons, together with nuclei of hydrogen, helium-4, and the intermediate nuclei.

Our capsule's sensors detect nothing more massive than helium-4. No nuclei of carbon, oxygen, nitrogen, silicon, or iron. Why? For the very same reason that the formation of helium-4 was delayed. Even when the final product was perfectly stable, certain intermediate nuclei, vital steppingstones in the process of "nucleosynthesis" were still highly unstable. Deuterium's temperature instability caused the holdup for helium-4 formation. Now, for anything heavier than helium, such as lithium-6, beryllium-9, boron-10 and carbon-12, it's the unstable nuclei with 5 and with 8 nuclear particles that are the problem.


Fermilab photo

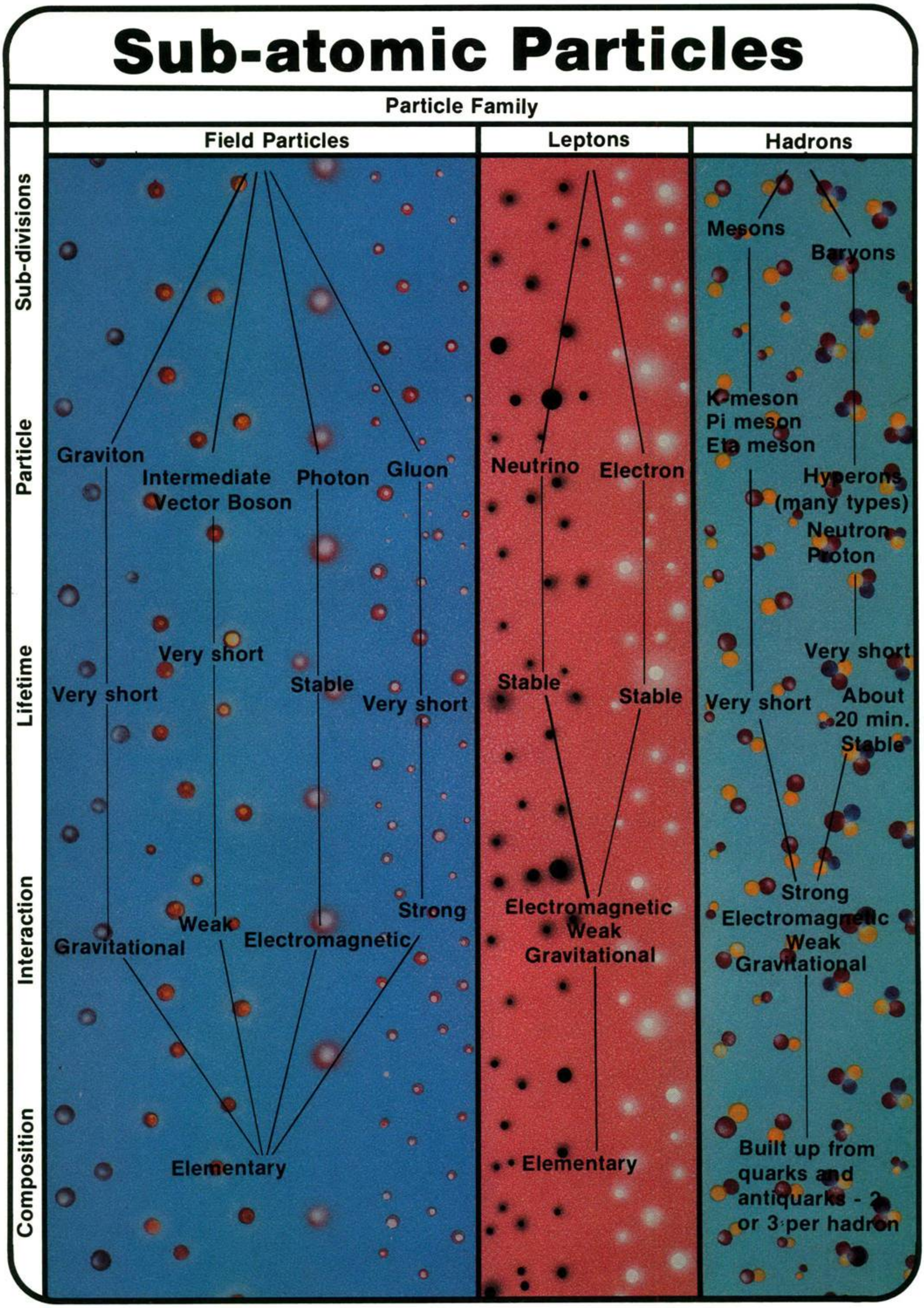
We wait. A half-hour slips by. The universe cools to a balmy 300 million degrees K — just 15 times hotter than at the Sun's core. Nucleosynthesis has come to a virtual standstill. Space will roughly double in size in the next hour if it's positively curved.

How is the energy within the universe distributed during the first hour after the Big Bang? Some of it is obviously tied up in the mass of particles like neutrons and protons and the nuclei they make up. Recall Einstein's famous equation, $E = mc^2$, linking energy with mass. The vastly greater bulk of energy, though, isn't in the form of matter at all. It exists, instead, as radiation.

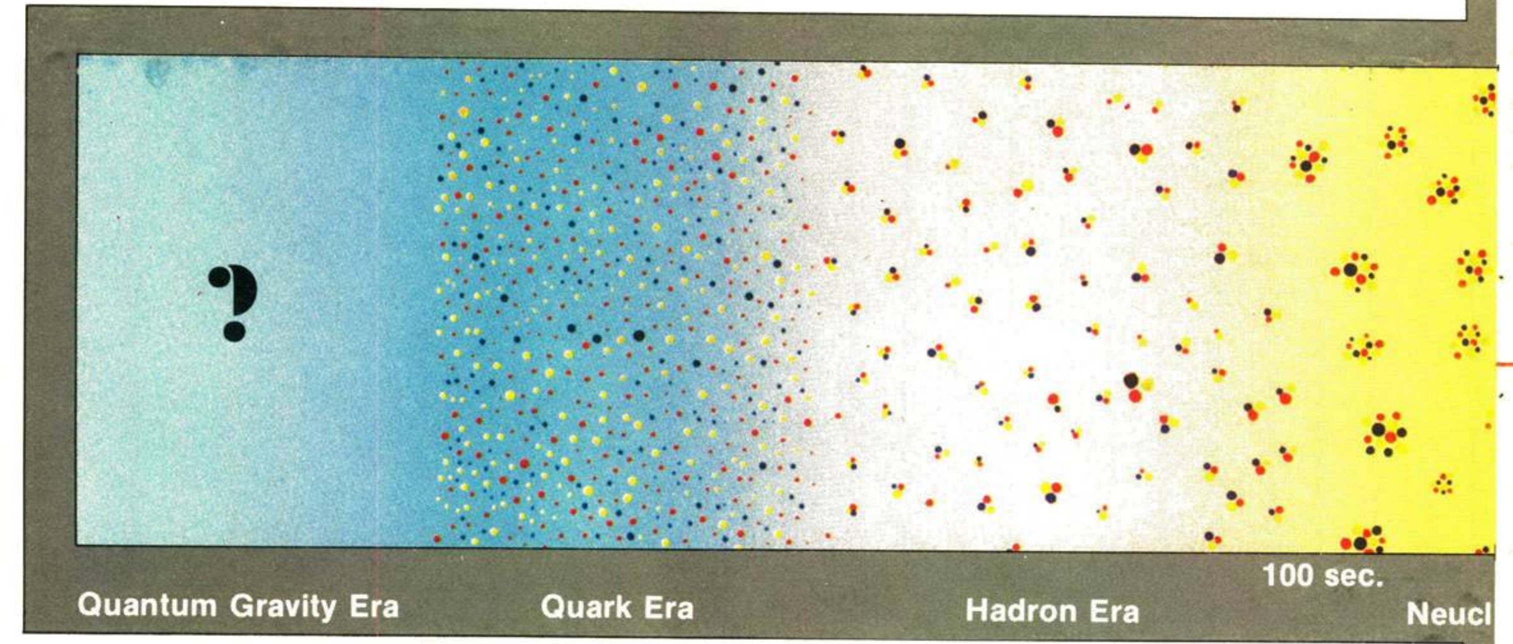
Laser bright in its intensity, the young electromagnetic field blasts apart anything resembling an atom. High-energy photons, bullets of pure energy, strafe the cosmos, instantly stripping away any electrons that dare to enter bound orbits around a nucleus.

Over half a million years later, the first stable atoms would form in a cooler universe. Matter and

Sub-atomic Particles



	Particle Family							
	Field Particles				Leptons		Hadrons	
Sub-divisions							Mesons	Baryons
Particle	Graviton	Intermediate Vector Boson	Photon	Gluon	Neutrino	Electron	K-meson Pi meson Eta meson	Hyperons (many types) Neutron Proton
Lifetime	Very short	Very short	Stable	Very short	Stable	Stable	Very short	Very short About 20 min. Stable
Interaction	Gravitational	Weak	Electromagnetic	Strong	Electromagnetic Weak Gravitational		Strong Electromagnetic Weak Gravitational	
Composition	Elementary				Elementary		Built up from quarks and antiquarks - 2 or 3 per hadron	



radiation would go their separate ways, and slowly the universe as we know it today would evolve.

We've reached to the end of the universe's first hour, and looked beyond. But we have an appointment to keep which can wait no longer. We must make our rendezvous with genesis.

Before the One Second Mark

Our versatile time machine eases back to the universe as it was just one second after the Big Bang. Outside, neutrons, protons, and the rest swelter in the 10 billion degree cosmic climate. Yet even at this early stage we've clearly missed a great deal. We still draw a blank on the vital question: Where did the particles of the 1-second cosmos — particles that we're very familiar with — come from in the first place? Did they just magically materialize from a dense blob of pure radiation energy or did they evolve from earlier, more exotic particles?

Again, we're moving. But now it's through microstrata of time separating the universe at one second from its unimaginable initial state.

The temperature rises to 100 billion degrees as we reach a point just 1/100th of a second A.B.B. Let's start to use compact, scientific notation and call it 10^{-2} second A.B.B.

The universe may be much hotter now, and denser, but the ancestors of the protons and neutrons, and of the lighter particles, electrons and positrons, vanished in a still earlier epoch.

All around us, the basic ingredients of matter as we know it remain unchanged. Cooking enthusiasts might note the recipe: roughly equal numbers of neutrons and protons, plus vast quantities of electrons, positrons, and the massless particles, photons, neutrinos, and antineutrinos. Stir thoroughly until the density is 4 billion times that of water and bake at 100 billion degrees. One cautionary note: sprinkle only lightly with nuclear particles. 10^{-2} of a second after the Big Bang, electrons, neutinos, and their *antiparticles* outnumber the more massive protons and neutrons by about a billion to one.

As we push further back, things really start to liven up within the newly-born universe. Ultra-high temperatures and ultra-high densities form the perfect environment for fast action in the world of subatomic particles. Two types of particle reaction dominate. Neutrinos ram into neutrons producing protons plus electrons. Protons, likewise, soak up antineutrinos to reappear as neutrons and positrons. Bang! A neutron turns into a proton, losing a tiny bit of mass but gaining a positive charge. Bang! The same bewildered particle is battered by a light-speed antineutrino and changes back into a neutron.

High-energy reactions between particles are becoming more frequent and more important as our capsule closes in on the moment of creation. Let's step into the "looking-glass" world of particle physics and discover exactly what's going on.

The Material of Matter

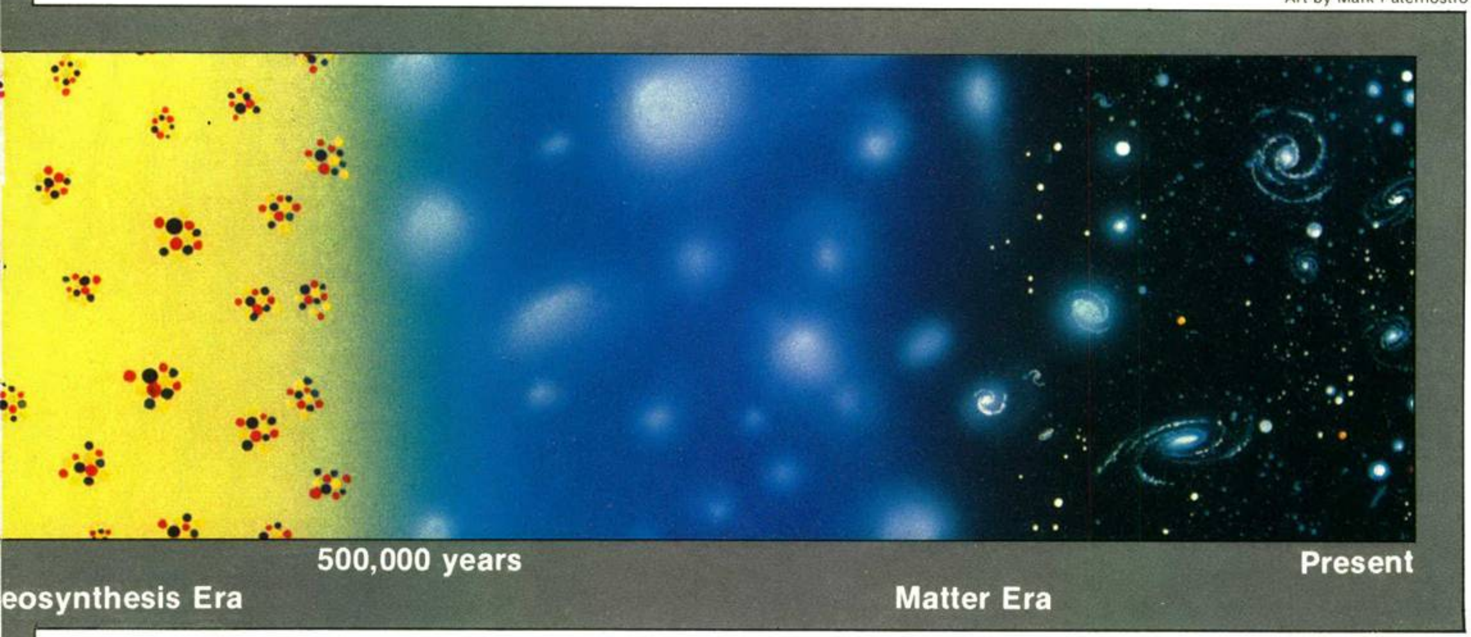
First, glance at the chart on page 19. In it you'll find a list of all the basic particles of matter and energy that we're interested in, and the three families into which they're grouped. Right away, you'll spot some old friends like the proton, neutron, electron, and photon. Don't be surprised, though, to see some oddball characters in there. In a hostile world, totally unlike our own, we'll be encountering a variety of new, exotic ingredients of matter.

Now think about the ways in which any two particles can interact. Think, in particular, about those four fundamental forces we mentioned earlier. What were they again? Gravity, electromagnetism, and the strong and weak nuclear forces.

Any two particles which have mass will pull each other through gravity. If they're charged, like the proton and the electron, they'll also feel an electromagnetic force. But what in the world are the strong and weak nuclear forces?

From our point of view, the weak nuclear force — the force underlying radioactivity and many particle "decays" — isn't too important. The strong force, though, plays a vital part in the very early development of the universe following the Big Bang.

So what is the strong nuclear force? To answer that, let's consider a simple atomic nucleus. The carbon nucleus is a good example. We find it to be made up from 6 neutrons and 6 protons, and to be very stable. How many diamonds have you seen that



Art by Mark Paternostro

have spontaneously exploded?

6 neutrons and 6 protons, hmm... Neutrons have no charge; protons each have a single elementary positive charge. Gravity plays no noticeable role at the atomic level.

But wait a moment. Diamonds should surely explode. Don't like charges repel? How can those 6 protons, each vigorously repelling the other 5 through the electromagnetic force, possibly live together in a stable nucleus?

Of course, there's only one answer. There must be a nuclear "glue" — another force, even more powerful than electromagnetism, which binds together particles in the nucleus. That force, the strong nuclear force, is what prevents the mutual electromagnetic repulsion of the protons from blowing the nucleus apart. Because it's important only over the tiniest of distances, we're never conscious of its presence in the everyday world.

Take another look at the chart. Notice, especially, the family of particles called *hadrons*. You'll see amongst the hadrons, in the heavy-weight group called the baryons, the familiar names of neutron and proton. As it turns out, not just the neutron and proton but every single particle in the hadron family can interact through the strong nuclear force.

How does all this tie in with events in the early universe? Let's look again through the windows of our time capsule and find out.

The onboard chronometer shows a time of just 10^{-4} of a second A.B.B. The outside temperature is a staggering 500 billion degrees K. And the cosmos has changed. No longer is matter made up from just a few simple components like protons and neutrons and electrons. Instead, one ten-thousandth of a second after the initial explosion, the universe is filled with a hot, dense, complex soup of heavy particles. We've arrived at the *hadron era*.

Densities are now so high that the strong nuclear force — a very short-range force — has become dominant. Living up to its name, the strong force is over 100 times more powerful than its nearest rival, the electromagnetic force. By comparison, gravity, the star crusher, is 10 trillion trillion trillion times weaker than electromagnetism!

All around the hadrons swarm. Neutrons and protons have been joined by their more exotic, short-lived cousins: the hyperons, pi mesons, K-mesons, and eta mesons. The further we travel back in time, it seems, the more complicated the universe gets. High-energy environments are ideal for producing great numbers of exotic, transient particle states.

Returning again to our chart we find these lighter particles grouped together in a very exclusive band called the leptons. How does a lepton differ from a hadron?

First, leptons can't "feel" the strong nuclear force. Electrons interact with protons, for example, only through electromagnetism. Secondly, leptons are probably truly elementary particles. Hadrons almost certainly aren't. Recent evidence from experiments at high energies suggests very strongly that hadrons are made up from even smaller components. Let's see how this exciting new evidence affects our understanding of the contents of the universe as we probe back to earlier and earlier times.

Around twenty years ago, cosmologists generally believed that the hadron era represented the very first state of development of the cosmos after the Big Bang. Not just the few hadron family members shown in our chart were involved. The idea was that for instants closer and closer to Time Zero, increasing numbers of more and more massive high-energy hadrons appeared on the scene. A tiny, hot dense microcosm rich with a fantastic variety of heavy hadrons is the picture which emerges.

But the picture now needs redrawing. Today, we know that hadrons aren't what they seem to be.

Take an atom — and split it. You'll find what appear to be the most basic components of all stable matter: electrons, protons, and neutrons. For many years following their discovery these particles were thought to be indivisible — to be elementary.

Electrons, together with the rest of the lepton family, have survived the test of time. Leptons, it seems, really are indivisible specks of matter. But what of the hadrons?

For some time, theorists had suggested that maybe the hadrons were really composite particles made up from even smaller entities called *quarks*. Today, we've enough evidence from experiments at a number of high-energy labs, to be able to say that quarks really exist.

There's only a small family of quarks, but they come in a variety of "flavors" with colorful names like "strange" and "charmed." Together with the leptons, they're now thought to be the only truly elementary particles of matter in nature.

All this has a decisive bearing on events in the earliest moments of the universe. It turns out that the hadron era no longer extends back to Time Zero. Look at the capsule's instruments as the outside temperature climbs to several thousand billion degrees. The hadrons have vanished.

Knowing that hadrons are really quark clusters — 2 or 3 quarks per hadron — it's not difficult to see what's happened. At temperatures as high as those we're now seeing, quarks can only exist in the free state. One ten-billionth (10^{-8}) of a second A.B.B., hadrons — bound quark states — are unstable.

Think how simple the universe now is, just 10^{-8} of a second after its creation. Gone is the hodgepodge of strongly interacting massive hadrons. In its place is a less torrid, far less complex mix of particles. Quarks, leptons, and their antiparticles, along with the ever-present barrage of photons, wander freely through the fantastically dense cosmos. The strange fact which emerges is that the closer they are together, the less force quarks exert on one another.

We stand ten-billionths of a second from the Big Bang. Quarks, each with the energy of a Saturn V in motion, race through space on their undisturbed flight. We ask: Is this the end of our journey? Does the quark era represent the very first evolutionary phase of the universe? No. There is one more step to genesis.

The Forces of Creation

Look again at our chart of particles. Look, specifically, at that one family of particles which we've so far ignored — the so-called *field particles*. Notice that our friend the photon is a member.

There's no mystery about field particles. They're exactly what their name suggests: tiny blimps of matter and energy which are present whenever a field exists. You'll find exactly 4 types of field particle — one for each field.

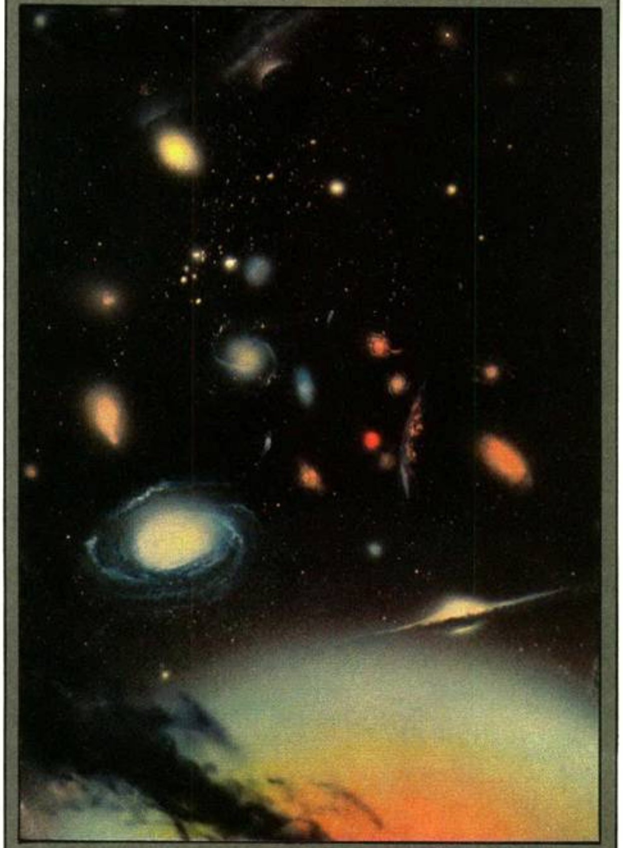
How do we fit the idea of "force" into this picture? Forces — gravitational, electromagnetic, or otherwise — come about through a continual bouncing back and forth of field particles. The force between, say, an electron and a proton occurs through the transfer of photons — quanta of the electromagnetic field — between the two particles.

A curious thing happens when field particles have super-high energies. They can spontaneously turn into totally new particle-antiparticle pairs. High-energy gamma rays, for instance, can suddenly transform into electron-positron pairs. The vast swarms of electrons and positrons which roamed the early universe were born in this way.

Like granules in the emulsion of a fine-textured film, field particles are the reality behind the four basic force fields of nature. As we delve deeper and deeper into the smallest strata of time separating us from the Big Bang, the granules of successively weaker forces come into focus. First, we encounter the quanta of the strong nuclear force as they burst into quark-antiquark pairs. Then the photons come into view, and we see the birth of electrons and positrons. The weak nuclear force has its heyday, too, with the cosmic temperature at around 3,000 million million degrees K. Gravity alone seems unaffected. Even as we cross the five trillion degree mark, the continuity of space-time remains unaffected.

One trillion trillionth of a second A.B.B., and we start to see the first grains in the structure of space-time. Particle-antiparticle pairs are beginning to seep out of empty space.

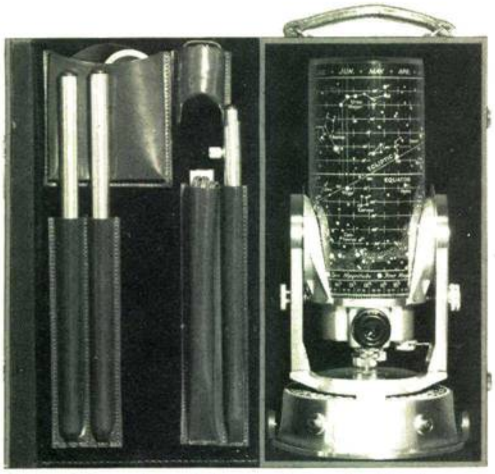
Finally we arrive. With the temperature at a mind-boggling 100 million trillion trillion degrees K, and the chronometer showing a time of just 10^{-43} of a second after the Big Bang, our capsule comes to rest.


Art by John Clark

Gravity is now the dominant force in the universe, overpowering even the strong nuclear force. High-energy gravitons shower everywhere, bursting spontaneously into particle-antiparticle pairs. The grain in the emulsion of space-time is finally revealed in all its detail.

And so we reach the end of our journey. A dark shadow stretches over even earlier times, obscuring our view of Time Zero. The shadow will only begin to lift when we finally succeed in unifying general relativity and quantum mechanics into an exciting new quantum theory of gravity.

David Darling received his doctorate in astronomy from the University of Manchester (England). His last article for ASTRONOMY was "Space, Time, and Black Holes," October 1980.



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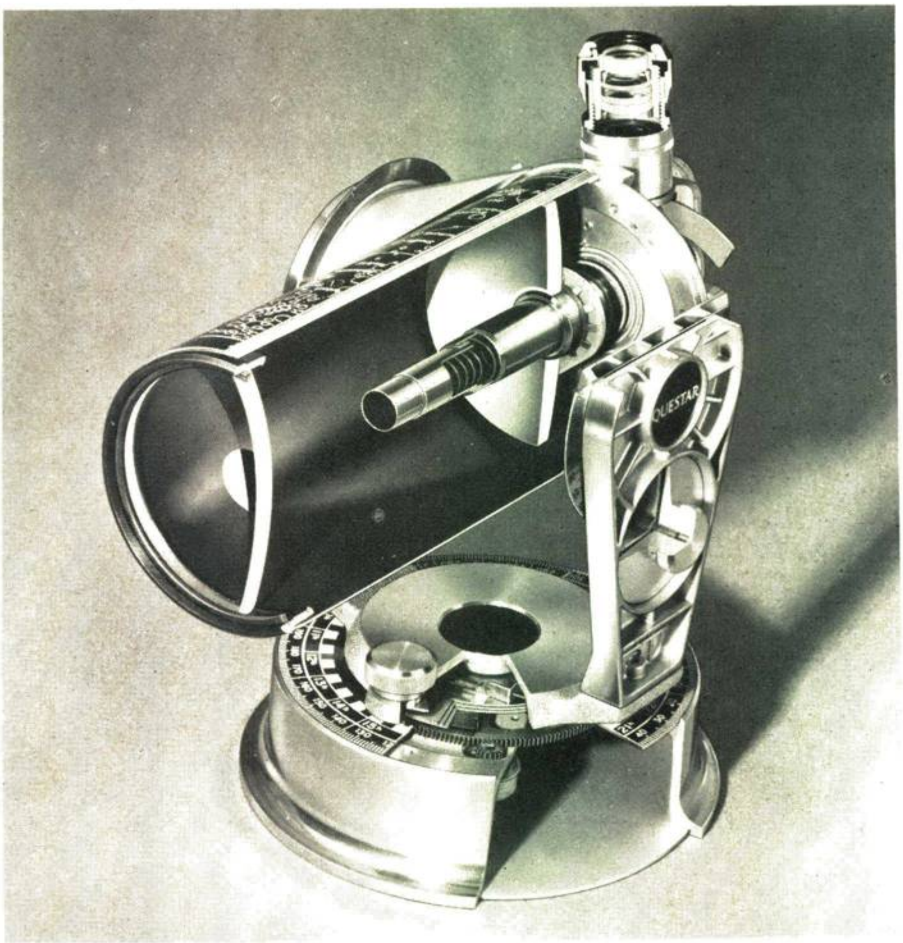

Our first ad in *Sky and Telescope* appeared early in 1954 and what we had to say was radical for its day. We had a new thing under the sun—a miniaturized version of the classical astronomical telescope. It was so small that it could be used on a table top and carried around in a leather case; a design that had built-in controls for finder, power changes, drives in right ascension and declination, both manual and electrical; and it could focus from infinity down to less than 10 feet.

We actually cut a Questar in half so that you could see what went on inside. The photograph shows the rugged construction of the fork-within-a-fork mount and the inner refinements, including the mounting of the mirror on its central support, with the careful machining and light baffling of the sliding tube. The internal motions of the mirror and power changes are all controlled by finger-flick knobs in the rear of the control box. In the base you can see the oversize gear that drives the scope without falter or backlash, and the three disks that give you such smooth manual following.

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ASTRONOMY
FORUM

An Interview with Garry Hunt

Garry Hunt is the director of the Laboratory for Planetary Atmospheres at University College London, in England, and an investigator on the Voyager Jupiter-Saturn Missions.

ASTRO: You've been deeply immersed in this mission for many years now.

GH: Right from the very beginning.

ASTRO: How many years is that?

GH: I've been on Voyager since 1972. Before that I was also with Grand Tour Mission, so it's a long, long while — about 10 years.

ASTRO: And what have you found most personally satisfying about this whole experience?

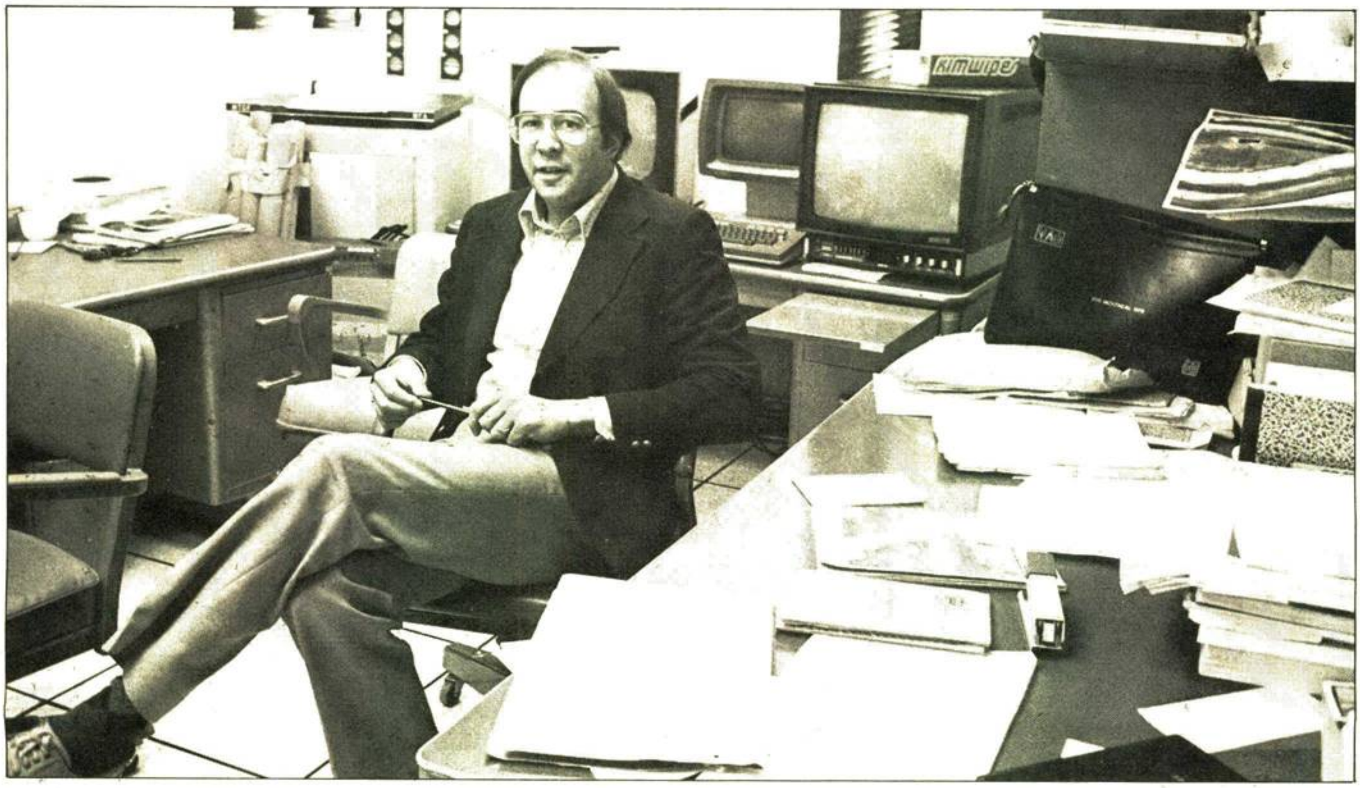
GH: I think the best thing of all is to have been in right from the beginning of the mission: to help design the instruments, to choose a trajectory, to plan what the sequence is going to be — and then see it pay off. I've been in from the very first breath, and survived the traumatic arguments, discussions, in-house fights that we've had just to get anything done.

ASTRO: Why was there conflict?

GH: Because there are certain trade-offs between scientific instruments. Everybody can't get just what he needs. But now, at the outcome of it, we can see we've run what must be the most satisfying project that the scientists participating are ever going to have in their lives. I'm proud to be part of that, part of a mission which has made marvelous discoveries not only in my own field, meteorology, but in the whole exploration of the solar system.

ASTRO: Can it help to restore public interest in space?

GH: I believe it has captured the imagination of mankind far more than anything we have done in a long while, probably as much we've done with some of the Apollo missions. We've really shown that we have a great deal to learn right here



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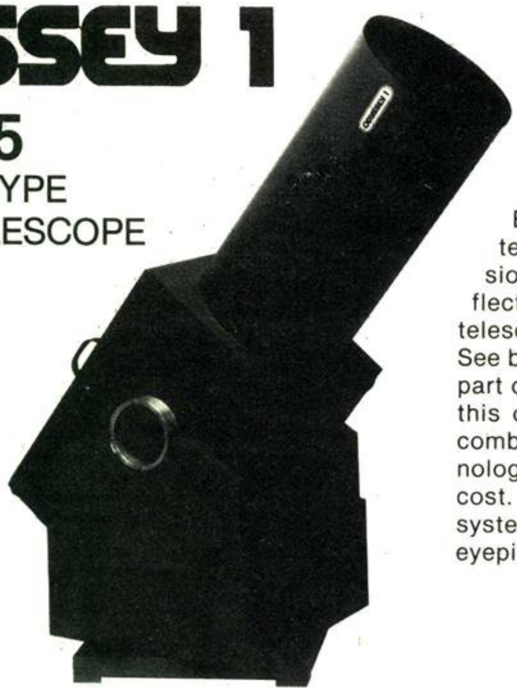

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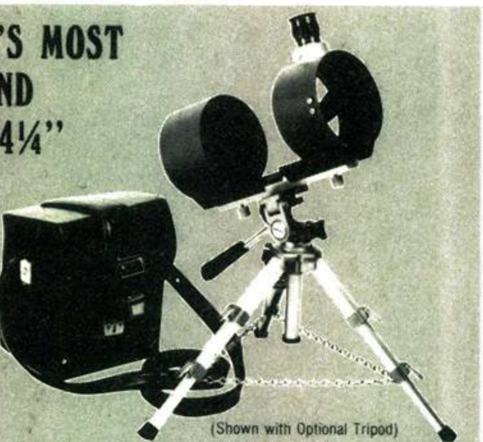

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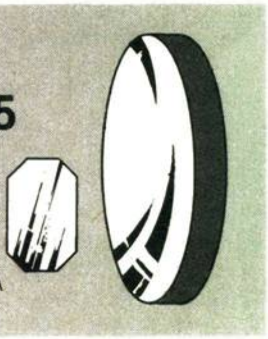

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in the solar system.

ASTRO: And for yourself?

GH: It's helped me to build up a very substantial research laboratory in London, where Voyager is one of our major research projects. This has certainly been able to develop through this involvement. And I've been very happy to be part of it. I look forward to another 10 years.

ASTRO: What do you anticipate we'll know about Jupiter in another 10 years?

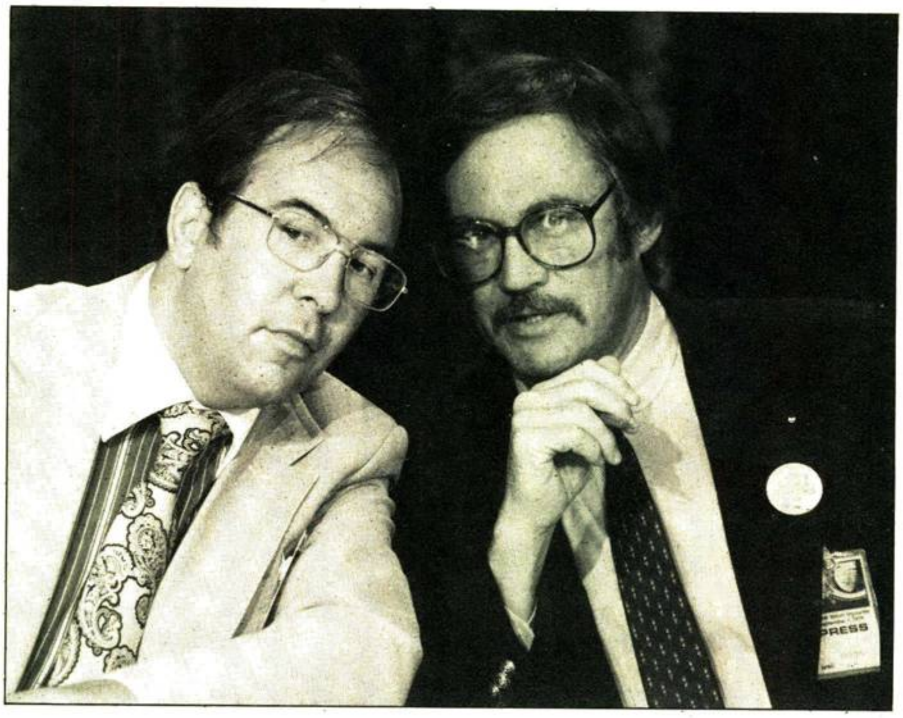
GH: The level of understanding of Jupiter will probably reach the level of understanding of some aspects of the Earth. I think the meteorology will be very well understood — and not just with Voyager. Voyager has given, after all, a myopic view of the planet because we see it for a short period of time. We'll basically be able to examine some of the energy diagnostics to understand what drives the flow. We'll also be able to use Space Telescope and watch Jupiter on a longer time base, with resolutions not terribly different from that we had with Voyager.

ASTRO: So the meteorology will be pretty sophisticated?

GH: We may be able to predict and simulate Jupiter's weather. We'll still be left with not knowing the forcing function, and may still be playing games with that, but I expect the meteorology of Jupiter will be very advanced and extremely quantitative. This is particularly nice because we're in a similar position with Venus and with Mars.

ASTRO: It's not just Earth alone...

GH: If we're ever going to understand basic geophysical flow-dynamics, we won't do it while looking at the Earth in isolation. Jupiter is a natural laboratory where wave interactions of the mean flow are dominant. It's a very important area for study.



ASTRO: What about Saturn? Shouldn't it fall into line with Jupiter?

GH: Yes, Saturn, this year, is going to be an interresting test of the models, because the models we used to describe Jupiter must also fit Saturn with just a few small deviations in some of the parameters. We may be feeling happy and successful now, but the big test is coming.

ASTRO: Are you ready for it?

GH: We are. We're also ready in knowing what we need to extract from the data. With Jupiter there are so many features to observe that we could obviously extract a vast amount of information. We expect Saturn to be more quiescent, more subtle, in its characteristics. But we'll know precisely how we should analyze the data. I think that we're in for a few surprises and a lot of excitement.

ASTRO: The data are not just pictures, but also the infrared...

GH: There are infrared measurements of atmospheric composition and structure. Polarimetric observations of the reflected sunlight and the ultraviolet measurements were made as well. We look at every portion of the electromagnetic spectrum to try to derive the information that we require, in the same way we do from the Earth. Meteorology is an integrated interdisciplinary science and we have to make sure we're using every instrument on board that's capable of adding to our knowledge.

ASTRO: Do you think that atmospheric models for the Earth will benefit?

GH: I don't want to make the claim that weather forecasting of the Earth is going to get better. I do think that the way we look at the Earth will change — and that will be for the better. And I believe our basic understanding of fluid mechanics, which is what meteorology is about, will improve dramatically.

ASTRO: The hard-rock astronomers have just been handed four new planets, Jupiter's moons. What would your reaction be, as an astronomer, if Jupiter itself had just now been discovered?

GH: That it's a very strange planet. That we've never seen anything like it before.

ASTRO: And as a meteorologist?

GH: As a meteorologist, it's surprising how similar Jupiter happens to be to the Earth. Now that may be surprising. As you are aware, the Earth's weather systems are driven by differential heating, by the large gradient of heat between the equator and pole. Terrestrial weather moves the energy from the equator to the polar regions. But Jupiter just does not have as much sunlight reaching the atmosphere; instead it has an internal heat source.

ASTRO: So you would expect some major differences?

GH: Yes. And another major difference, of course, is the spin rate. Jupiter rotates very quickly compared to Earth. That, I think, makes a lot of the differences we do see.

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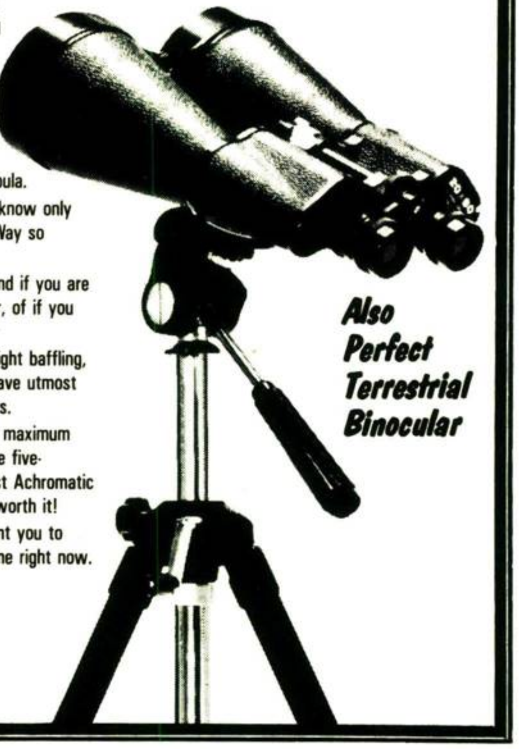

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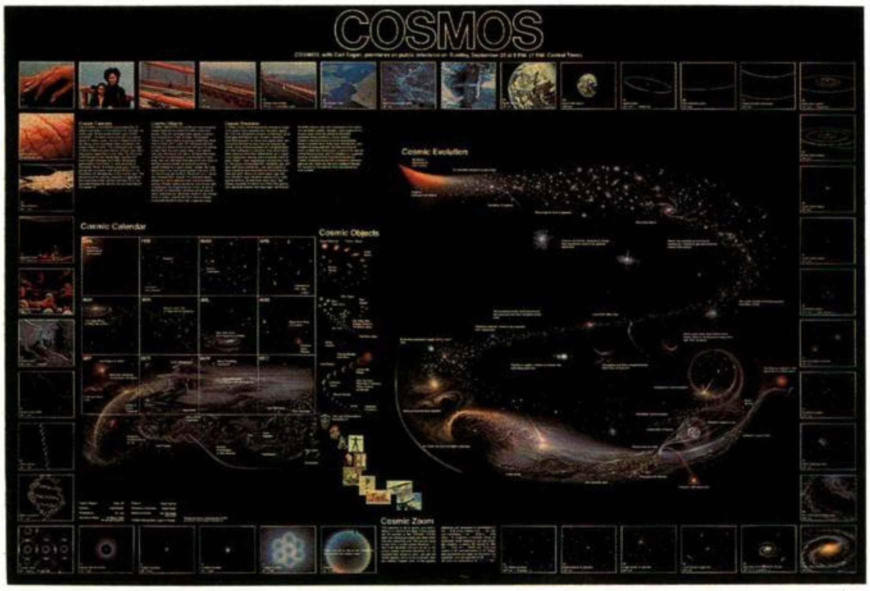

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ASTRO: The pictures we've seen are very pretty, but I'm sure you haven't just looked at and admired them.

GH: Oh no — we've been able to use interactive image processing techniques to measure the clouds and build up a very large statistical package of the basic cloud velocities. From that we've been able to make some very detailed interpretations of Jupiter's meteorology. When we produced our zonal wind profile, a chart showing how everything moves in Jupiter's atmosphere in an east-west direction, we noticed that the values that we obtained compare very favorably with those obtained from the Earth.

ASTRO: The zonal wind profiles obtained by Earth-based telescopes must rely on large features only.

GH: That's correct. The initial Voyager studies concentrate on features just a few hundreds of kilometers across. When you look at smaller and smaller scales and you still extract the same velocity, it means you're seeing mass motions and not just waves passing through. Another thing is that when you look at Jupiter's cloudbelts, you notice the asymmetry between the hemispheres. The northern hemisphere does not have large-scale features like the southern hemisphere's Red Spot and ovals, and it has a different belt-zone structure. Immediately you can see that the clouds in the two hemispheres are quite different.

ASTRO: I see. But the velocity profile *is* symmetric about the equator.

GH: At first sight you may believe that these two things are in conflict. What it tells you, though, is that the jets are long-lived features of Jupiter's atmosphere. They agree with Earth-based observations which have been made over a long period of time. Their symmetry suggests there must be factors well beneath the visible clouds controlling these jets.

ASTRO: So the visible clouds are superficial, and the jets are driven by something deeper.

GH: We do not know what's going on beneath the visible clouds. But somewhere, probably hundreds of kilometers below the levels we probe with Voyager, must be a boundary which is very important in controlling the long-lived features.

ASTRO: By "long-lived," you mean the belts and the zones?

GH: Yes, and secondly I mean the Red Spot, white ovals, and perhaps even the plumes as well — since they are relatively long-lived features. Beyond that, of course, the most fundamental question to answer about Jupiter's meteorology is why indeed Jupiter has belts and zones at all. That's something which we shouldn't shrug our shoulders at. It is perhaps the most fundamental question of all.

ASTRO: And you want to determine how they are driven?

GH: Of course. But we're just at the start. We have only something like 160-200 days of the data, and we haven't analyzed much of that yet. We've only looked at barely two days worth in sufficient detail, where we've actually produced a velocity pattern over the entire planet.

ASTRO: What about the Red Spot?

GH: The one thing that we've tried not to do is to examine the Red Spot in isolation: it has to be part of the general circulation. One clue to this is the decline of the white ovals which we have seen over the last 40 years. From being an enormous zone in 1940, they are now just three large pieces of cloud only 11,000 kilometers long. The Red Spot itself has gotten smaller. Over the last 100 years, in fact, it's reduced from 46,000 to 21,000 kilometers in length now. And so the working hypothesis is that perhaps ultra-long waves are associated with the belt-zone structures. The large scale features manifest themselves on these waves, and become stable — or apparently stable — for long periods of time.

ASTRO: You've more than answered my question, "Has Voyager been sufficient for a basic understanding of the jovian atmosphere?", and the answer is "Yes, it has."

GH: Yes, it has. Quite emphatically.

ASTRO: Would you like to add anything else?

GH: Yes. I think that as resident foreign national, I carry some "extra" responsibility. As a foreign national, I am doing a lot for my own country in participating in this major mission. I'm also adding something, contributing, to a very important NASA mission. I acknowledge that responsibility, and I acknowledge the privileged position. I'm just very grateful to be in it, and I hope that I have been able to contribute significantly toward it. I've certainly enjoyed it, and I've got a lot out of it, but I hope that the whole mission has benefited a great deal from having me participate.

Shrine to the Stars

Stellafane — the very word is filled with magic. Even for those who have never journeyed to the verdant hills of Vermont, it conjures up images of lovingly wrought optical creations in glass and metal, mirror and wood.

For the many who have set foot on "Breezy Hill" but once in a lifetime (having traveled from distant states or even flown from alien shores), Stellafane will forever evoke memories of the finest in Yankee ingenuity applied to the art of amateur telescope making.

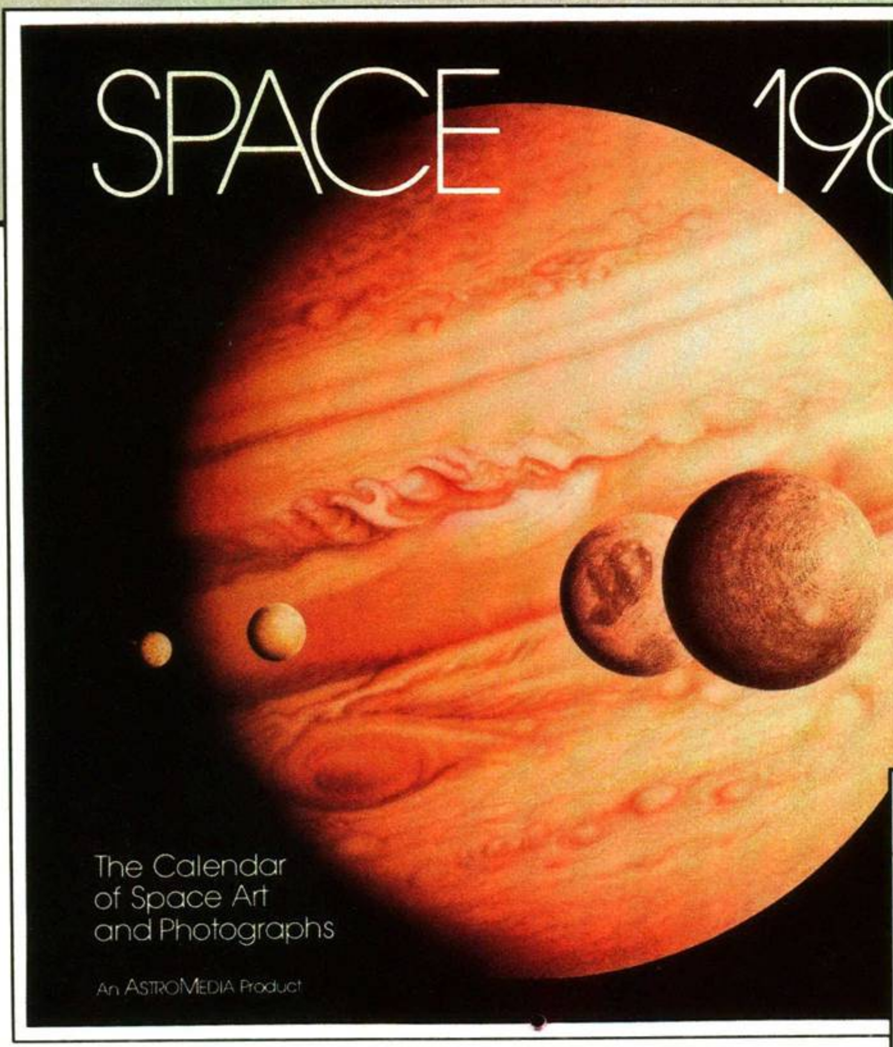
For the fortunate who yearly make the pilgrimage to the pink shrine atop the hill, the historical landmark has become a jousting ground of friendly competition for optical excellence and craftsmanship, where tournaments are won by the length of a wave of light.

For it was here, in Springfield, Vermont, not far from the banks of the Black River, that ordinary men and women, half a century ago, first combined the accuracy of their tool-making skills with the patience of mirror grinding, culminating in the creation of the first amateur telescopes in the world.

The ingredients were all at hand: the micrometer-artisanship of the inhabitants of "Precision Valley" who filled the growing needs of American industry for castings, bearings, and gears — masters all, but men whose horizons were limited by the seemingly inescapable routine of their daily travail. All that was needed was a catalyst, the single spark of genius whose presence would transcend the social barriers of the day and would lift the machine-bound factory workers beyond the confines of their mills, up and out to the very edge of the universe.

His name was Russell W. Porter, himself a Vermonter, an engineer, arctic explorer, inventor and visionary; friend to man, a lover of the stars, it was he who first set out to instruct a group of fifteen men — mostly Springfield machinists — and one woman — a school teacher — in the art of fashioning their own mirrors. Soon after, he would teach them how to construct and use their own telescopes.

They met for the first time on August 17th, 1920 in the "foreman's room of the Jones & Lamson Machine Co." to chart the course of their endeavors. By December 1923, they had formed a club which called itself the "Springfield Telescope Makers," and elected Russell Porter its first president. Half a century ago, *eventually with help from the Boston* A.T.M.s, the club began to host its annual gatherings. Individuals and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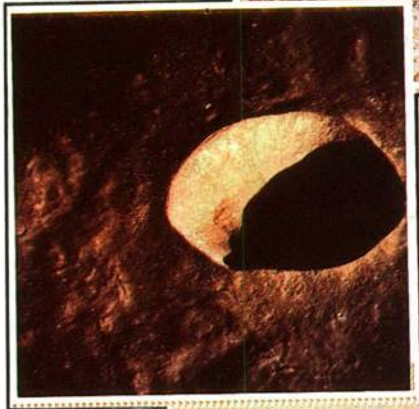

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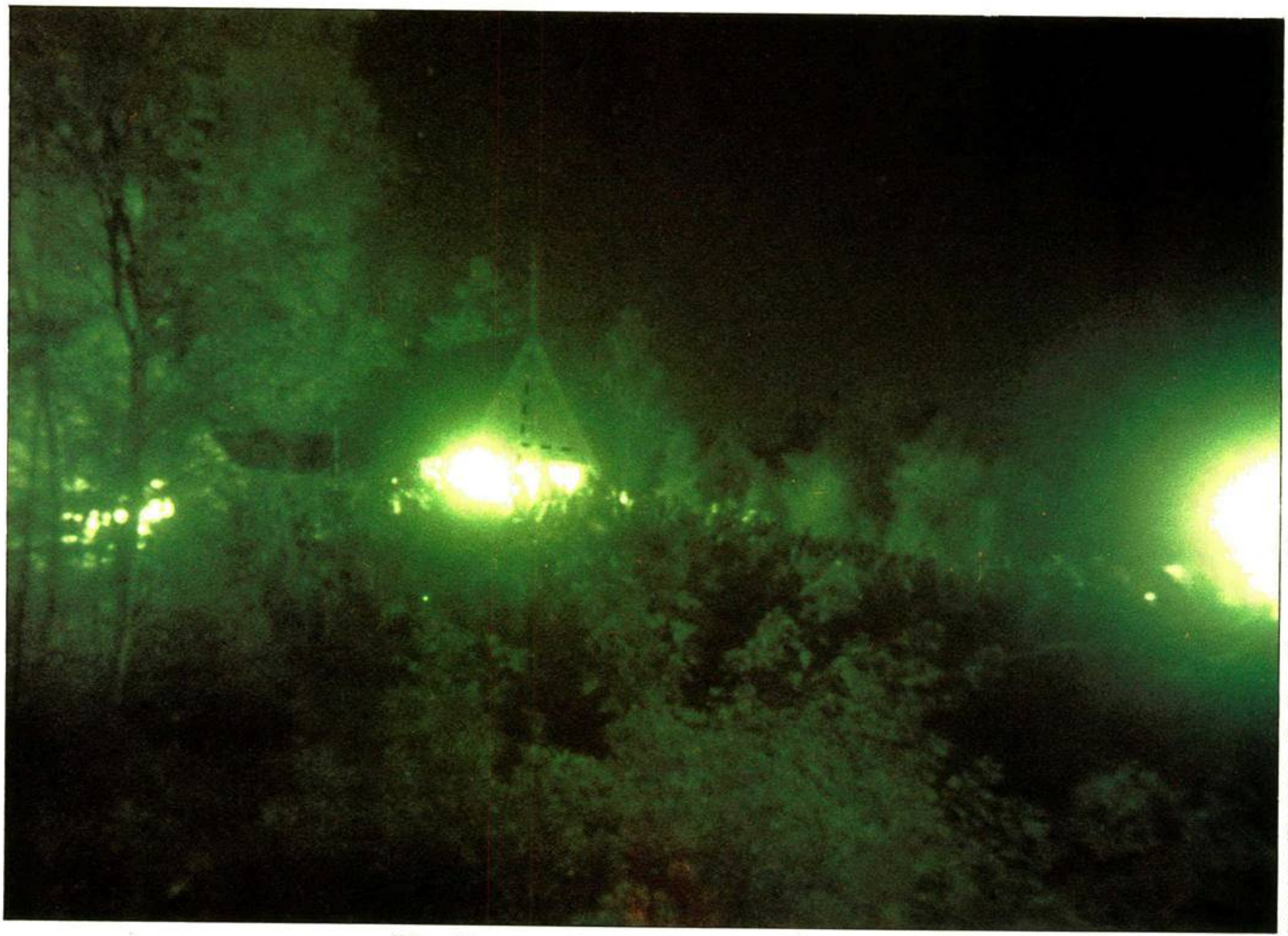

Image intensifier photo by Ben Mayer (2 sec. exp., f/1.4)

"The Heavens Declare The Glory Of God"

members from other groups were invited to display the products of their skills. In due course, prizes for superior craftsmanship and optical excellence in telescopes were awarded.

That was the beginning of "Stellafane" as we know it today. Since the very outset, the event has taken place in and around the little gabled pink house on land owned by the Springfield Club.

Berton C. Willard, a prime mover in current Stellafane gatherings, chronicles the history and the generosity of Russell Porter: "Porter had inherited the land on top of Breezy Hill in 1906. At first he leased it to the Springfield Club but finally sold it to them for one dollar."

The clubhouse, beloved of thousands of "Stellafaners" was completed in 1924. Records show that it was again Porter who contributed $314.35 for building materials, and it is believed that James Hartness, an avid amateur astronomer and governor of Vermont, contributed the balance.

Concerning the color of the clubhouse: It seems that a local merchant contributed the paint for the building — and it just happened to be pink. To this day, the gabled cottage has been maintained in that color.

Scientific American was the first major publication to spread the story of "Stellar Fane" — Shrine to the Stars — as it was originally named. Their first articles resulted in an increased public interest in amateur astronomy and, since then, a steadily growing participation in astronomical pursuits. (TELESCOPE MAKING will report, in words and pictures, this year's award-winning innovations as well as the names of the outstanding amateur telescope makers.)

The recent 45th Convention followed the classical format. Friday evening and Saturday afternoon, many interesting papers were presented, most illustrated with slides. Topics ranged from the humorous and practical astrophotographic experiences of David Healy to new ways of using Projection Blink Comparators by Gerald Dyck.

Friday night, clouds did not permit the use of the telescopes which had been set up. But on Saturday the weather turned glorious, and we knew the daytime judging of the instruments for their construction and craftsmanship would be followed by optical evaluation that night.

The Saturday evening program, presided over by George T. Keene, began with words of welcome by Vermont Governor Joseph B. Johnson and the customary twilight shadowgram by Walter Scott Houston. The featured speaker was the Master of Ceremonies himself, who took his audience on an eclipse tour to Kenya and Egypt.

As one who has himself been shown the privilege of being invited to be the keynote speaker at Stellafane (in 1978), I was again reminded of the uniqueness of the audience, sprawled in the darkness of the hill and waiting to be regaled with stories about the stars. Some sit on chairs brought from the nearby campsites; others recline on the grass or on blankets spread over the native Vermont rock.

Above it all, an endless roof over a vast auditorium, the night sky extends. Often clear, sometimes misty or cloudy, the stars remind all *present of the heavens beneath* which we pursue our daily lives. To most people the day ends with the setting of the Sun — only the starlovers seem awake to the loveliness and the mystery which surrounds our lives once darkness descends.

Perseid meteors, those sparkling harbingers of autumn, etch lazy or hurried lines into the velvet firmament. Only the fainthearted speaker would feel upstaged by their magnificence and the gasps of delight which they elicit from the listeners. For these shooting stars are a part — an intrinsic part — of what Stellafane is all about.

Stars, falling stars, novae, supernovae, and cataclysmic exploding suns must all suggest, to speaker and audience alike, their fleeting presence on this one small planet we call Earth. In hearing about Stellafane meetings long past, one cannot but become aware of the transience of all who have trod this hill, and spoken or lectured.

For one brief moment they proudly stand, holding forth about light-years, about Einstein remembered, or the tombs of Egyptian kings. Publications may cover these proceedings, filling pages that will quickly yellow with age. The participants in the events may record each other with photographs, brief flashes cut out of time. Then, having soared like meteors, the speakers will vanish. The stage will yield to succeeding personalities, and their names may in turn briefly illuminate the pages of journals yet undreamed of.

Could it be that this is why so many among the ranks of astronomers are engaged in searches or quests for discovery? Might the hunt for the comet be merely a means to the end of having one's name immortalized through all time, or at least for as long as astronomical records are kept and preserved? Is it possible that anyone engaged in the pursuit of a search is also secretly seeking the ultimate reward of being linked, for all time, with the stars?

There is no place like Stellafane. Here the amateur is celebrated as the lover he should unashamedly be. It is here, for three exhilarating days, that commercialism is frowned on. It is here ingenuity and resourcefulness triumph. It is as if friendships entered into on Breezy Hill are forged under the stars to be more lasting.

The spirit of Stellafane is epitomized in the brief legend which is carved into the angled fascia boards on the clubhouse itself. It simply states:

THE HEAVENS DECLARE
THE GLORY OF GOD.

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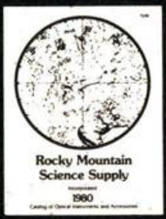

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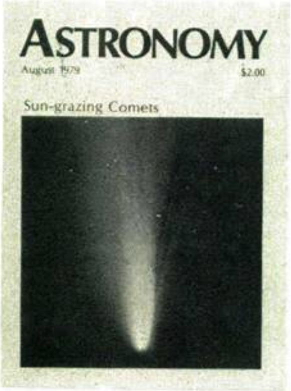

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Topical Index

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Venus — Aug 76, April 79, Jan 80

Earth — Sept 75, Mar 76, April 76, Feb 78, Aug 78

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Cosmology

Nov 75, Mar 76, May 77, Aug 77, Mar 78, Sept 78, July 79, Aug 79, Oct 79, Mar 80

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eye
on the
sky

planets cluster in the predawn sky

the wanderers

With the sole exception of Mars, there's little for a naked-eye planet watcher to see during the long evenings of November. To catch sight of the other four "classical" objects, set your alarm clock early — they are all in the morning sky.

From the first of November to the last, **Mars** is a dimmish point of light, low in the southwest at day's end. Though far more ruddy, its brightness slightly surpasses that of Alioth, the first star in the Big Dipper's handle. About 45 minutes after sunset, when the twilit sky is well along toward dark, look for Mars about as far above the horizon as the width of your palm held at arm's length.

On the evening of the 10th, you'll see a 3-day-old crescent **Moon** near Mars, above and a little to the right of it.

But compare this with the morning sky's program of events!

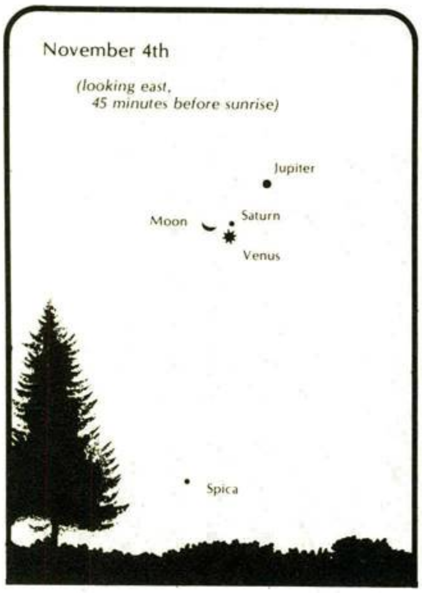
On the mornings of the 3rd, 4th, and 5th, a glance to the east 45 minutes before sunrise will reveal three planets, the Moon, and two stars. Highest of the three planets is bright **Jupiter**, white in color. Below and to the left lies yellowish **Saturn** and, directly below, brilliant **Venus**; 'way down by the horizon is white **Spica**, the brightest star in the constellation of Virgo. Over to the left and somewhat higher is orangy **Arcturus**, the luminary of Bootes, the herdsman.

Down through them sweeps the Moon: on the morning of the 3rd, it is a slender crescent above Jupiter. On the 4th, it'll lie just to the left of Saturn and Venus. By the 5th, you'll see it to the upper left of Spica, about level with Arcturus, the lunar crescent having become very thin.

This leaves only one naked-eye planet unaccounted for: **Mercury**. As if waiting for its cue, this elusive object pops up into view in the east around the 10th of November. You can spot it if you look very low in the east-southeast 45 minutes before sunrise. Over the days to follow, it'll climb swiftly higher each morning, reaching maximum height on the morning of the 19th.

Joining it on this same morning is the quintet (Jupiter, Saturn, Venus, Spica, and Arcturus) you watched two weeks earlier. Only the Moon, now nearing full, is missing.

On the same evening that it becomes full (the 22nd), the Moon will pass through a spray of stars known as the Hyades cluster (see Skylore below for more on the Hyades). The best view is in binoculars, because the moonlight will wash out all but the brightest stars. But it's still well worth a look to the east as the Moon rises.



The best by far of November's annual **meteor** showers is the Leonid display, which reaches peak numbers early on the morning of the 17th. Leo, the constellation they appear to come from, is well up by about 2 a.m. local time. If you bestir yourself and go out, you can expect to see about 10 to 15 per hour.

the starry sky

If you go out around 6 or 7 p.m. on a mid-November evening and look up, you'll see a curious amalgam of three distinct seasons: Summer, Fall, and Winter. Overhead and toward the west, run Summer's starry groups — Cygnus, Lyra, Aquila, Scutum, the Milky Way. Arrayed before you in the south lies Fall: Aquarius, Pegasus, Cetus, Andromeda. Rising in the east are the glories of Winter — Taurus, Orion, Canis Major — though these won't become prominent until around midnight. Let's browse through this assortment and pick up whatever strikes our fancy.

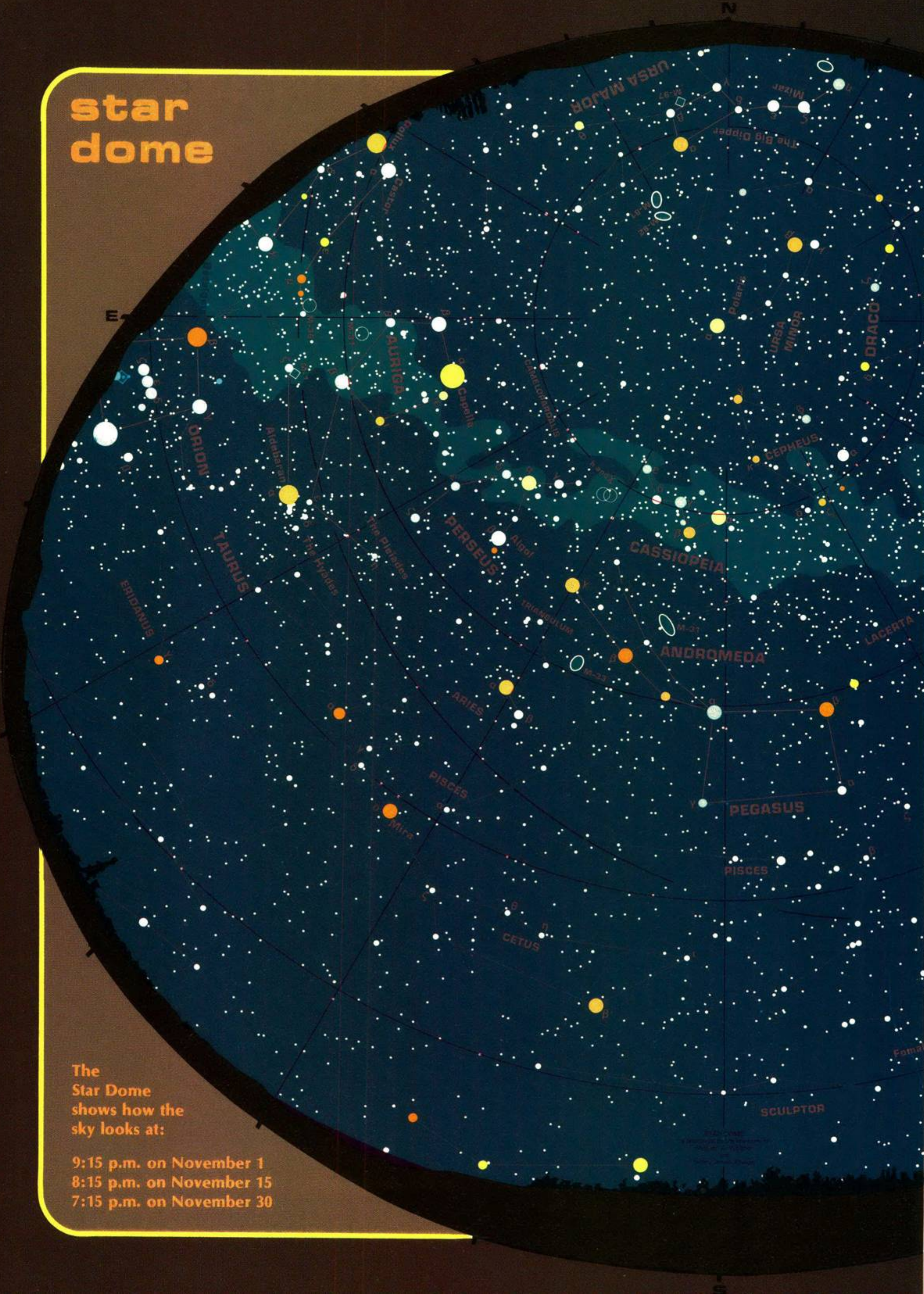
Starting in the southwest (for this region will set soonest), scan along the **Milky Way**. Down on the horizon, and dipping under about now, is **Sagittarius** (the archer), a moderately bright group with an uncanny resemblance to a teapot.

Just north from Sagittarius lies **Scutum** (the shield), a relatively inconspicuous constellation amidst the rich star-clouds of the Milky Way. Directly north of that lies bright **Aquila** (the eagle), which has first-magnitude Altair as its beacon. **Altair** is one-third of the **Summer Triangle**, an informal grouping of **Deneb** (in Cygnus) and **Vega** (in Lyra), that becomes visible in the early Summer and stays prominent until late Fall.

Cygnus (the swan, also called the **Northern Cross**) appears to be flying

A bright Perseid meteor streaked away from Polaris, the pole star, during the 45 minutes Martin Anderson ran his exposure. Another Perseid, much fainter, lies near the center of the photo. His lens was a 50 mm f/2.8 "normal." (For more photos of the Perseid shower, see pages 102-104 in Through the Eyepiece.

star dome


N
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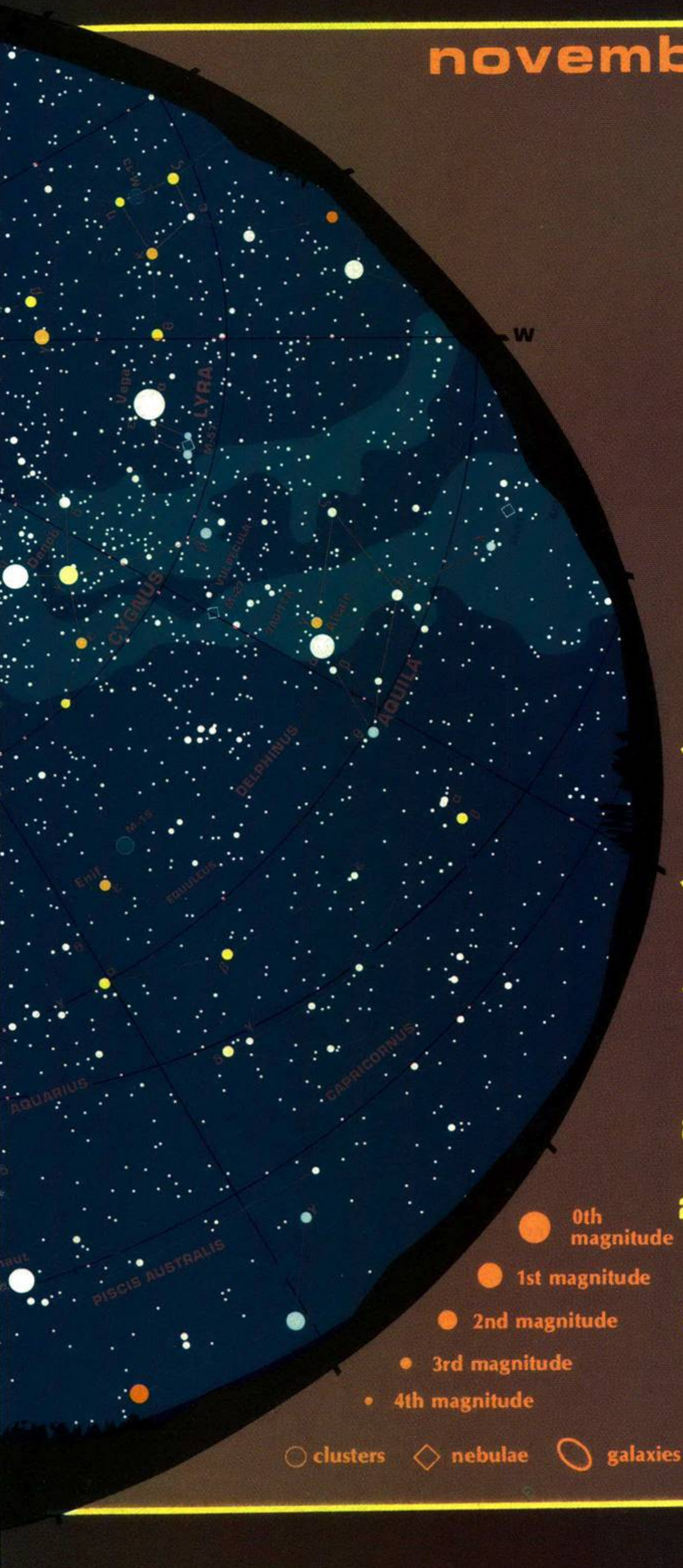
ANDROMEDA
LACERTA
ERIDANUS
ARIES
PISCES
Mira
PEGASUS
PISCES
CETUS
SCULPTOR

The Star Dome shows how the sky looks at:

9:15 p.m. on November 1
8:15 p.m. on November 15
7:15 p.m. on November 30


W
M-13
Vega
LYRA
M-57
Deneb
CYGNUS
VULPECULA
M-27
Altair
AQUILA
DELPHINUS
M-15
Enif
EQUULEUS
AQUARIUS
CAPRICORNUS
PISCIS AUSTRALIS
0th magnitude
1st magnitude
2nd magnitude
3rd magnitude
4th magnitude
clusters
nebulae
galaxies

november sky almanac

3rd Mercury passes between the Earth and Sun today, shifting from the evening sky into the morning. Start looking for it low in the east before sunrise about a week from now. Also, there's a fine array of the Moon and planets in the predawn sky today, tomorrow, and Wednesday.

5th Moon is farthest from Earth (apogee) today at noon EST: 251,982 miles.

7th New Moon comes at 3:43 p.m. EST.

9th Mercury is closest to Sun: perihelion.

15th First Quarter Moon happens at 10:47 a.m. EST. Good time to look for craters on it with a telescope.

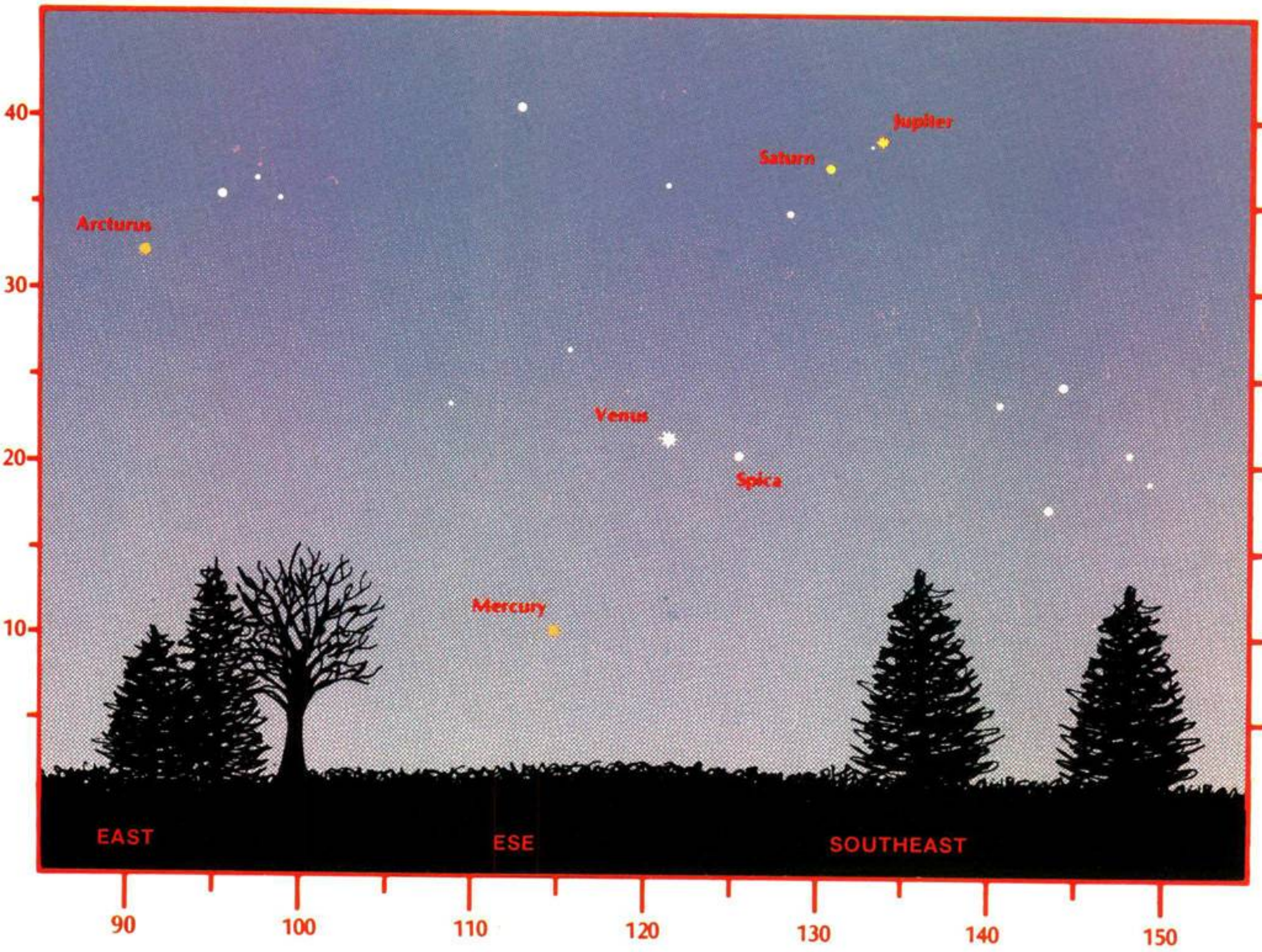
16th Tonight and early tomorrow morning: the Leonid meteor shower.

19th Mercury is at its widest separation from the Sun in the morning sky. Best day to look for it.

20th Moon is closest to Earth (perigee) at 8 p.m. EST: 222,741 miles.

22nd Full Moon at 1:39 a.m. EST today. Tonight, it passes through the Hyades cluster.

29th Last Quarter Moon comes at 4:59 a.m. EST. In a few days, it'll be near Jupiter and Saturn.



The morning sky on November 19th will reveal a fascinating array of planets and stars. The view above shows what you'll see if you go out 45 minutes before sunrise and look east-southeast. You will see much the same pattern during most of November, so if weather's poor on the 19th, don't give up hope!

south along the Milky Way, perhaps heading for warmer climates! **Lyra**, to the right of the Milky Way when you face west, completes the Summer Triangle with Vega, and in a clear sky does resemble its namesake at least a little.

North from Cygnus, the next bright constellation is **Cassiopeia**, a group easily recognised by its "M" or "W" shape. (When you face north around 7:30 p.m., it looks like an M, hovering above **Polaris**, the pole star.)

To the south of Cassiopeia, spread the Fall constellations. The closest of them to Cassiopeia is **Andromeda**, a small spray of stars second magnitude and dimmer. The constellation's brightest star, **Alpheratz**, is shared with Pegasus (the flying horse), which adjoins it to the southwest (lower right).

If the night is very clear, in northern Andromeda you can see a faint patch of haze. This is the most distant object visible to the naked eye: the **Great Galaxy** — a near twin of our own Galaxy, almost 2½ million light-years away.

In **Pegasus**, the most distinctive part of the constellation is the so-called **Great Square** — which you can't miss since it looks just like its name! We mentioned that Alpheratz, on the Square's upper left corner, belongs to Andromeda, but the rest of the stars in it, **Scheat** (upper right), **Markab** (lower right), and **Algenib** (lower left) are all true "Pegasians."

Below Pegasus and to the right lie two dim zodiacal constellations, **Aquarius** (the water carrier) and **Capricornus** (the goat). Neither has any star brighter than third magnitude and so are often overlooked by people viewing from typical urban or suburban areas. Only when you get out under rural skies do you begin to see these two and other dim constellations as they must have appeared to the ancients who created them.

To the southeast (lower left) of Andromeda and Pegasus lie three relatively inconspicuous constellations, two of which are zodiacal: **Aries** (the ram), **Pisces** (the fishes), and **Cetus** (the whale). Aries, which lies on the zodiac, would never win any prizes for brilliance. Its brightest star, **Hamal**, is only second magnitude and the rest quickly fade down into obscurity, forcing you to work your imagination a little to see a ram here!

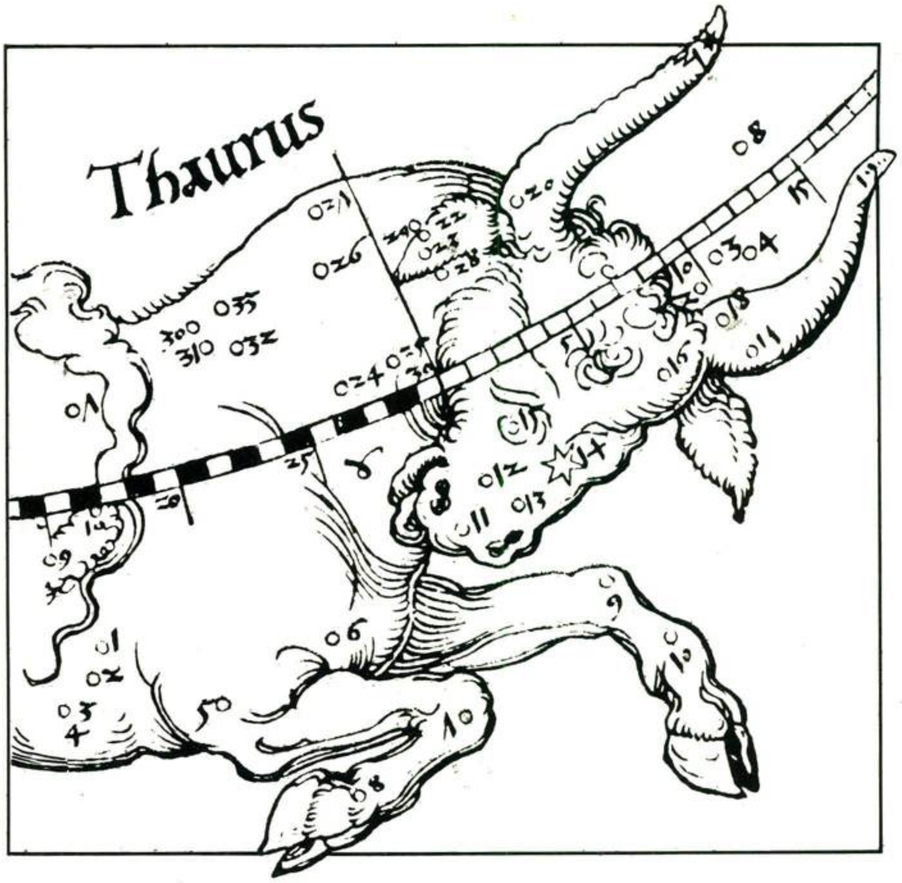
Pisces (also zodiacal) purports to be two fish, their tails tied together by a long cord. One fish lies below the Great Square and shows as a circlet of fourth and fifth magnitude stars. To the east (left) from here extends a line of dim stars — the cord — which stops at fourth magnitude **Alrisha** ("the knot"). The cord continues north and west from Alrisha, stretching up between Pegasus and Aries to the second fish.

Below Alrisha swims **Cetus**, a large sprawling constellation with many third and fourth magnitude stars and one very unusual one. The brightest is **Deneb Kaitos** (second magnitude) which lies about where the whale's mouth ought to be. But in the middle of the whale's tail lies a famous red variable star, **Mira** ("the marvelous").

Mira's brightness changes slowly from third magnitude to about 10th over a period of 331 days. It was at maximum brightness around September 12 and is now fading. For how many weeks more can you keep it in sight?

By now, it's middle to late evening.

Summer has set and Winter's groups are rising: heralded by the Pleiades and Hyades clusters in Taurus, Orion's retinue glitters in the east. Farther below lies Canis Major and its flashing diamond, Sirius. To the north and overhead, five-sided Auriga (with its *lucida* Capella) and Perseus are in view...but let's save Winter's splendors for another night!



skylore

In ancient times man turned to the heavens for clues to happenings on Earth. It was soon noticed, no doubt, that the changing of the seasons had its exact corollary in the changing appearance of the night sky, and it was only natural that certain constellations and groups of stars became associated with specific times of the year. We see this today in such titles as the "Summer Triangle," and the image of Orion as the Hunter of Winter. Sirius, the "Dog Star," gave its name to the "Dog Days" of August, which follow the time of its heliacal rising (when it first appears in the eastern sky just before sunrise).

One of the more impressive stellar groupings with earthly meteorological associations is the striking naked-eye star cluster known as the Hyades, gathered around (actually behind) the brilliant first-magnitude star Aldebaran in Taurus. The very name "Hyades" has been understood to mean the "Rainy Ones," although some, as we shall see below, derive the word from the Greek name Hyas. Their watery character is testified to by these lines from Tennyson's *Ulysses*:

Thro' scudding drifts
The rainy Hyades vext the dim sea.

Interestingly enough, the Hyades have been associated with rainy weather all over the world, including China where they were worshipped as Yu Shi, the Ruler of Rain. Capella and the Kids, located in the constellation Auriga a little farther to the north of the Hyades, are also considered a sign of storms and rain. These associations undoubtedly arise from the fact that both these groups are visible all night long beginning in November, the month when unsettled weather begins in northern temperate latitudes.

In his *Celestial Handbook*, Robert Burnham, Jr. notes that an even more sinister association for the Hyades has been recently made by H.P. Lovecraft. Lovecraft, the author of the frightening Cthulhu Mythos stories, locates the "Lake of Hali" on "a dark star near Aldebaran in the Hyades." This Lake, according to Lovecraft, is the haunted place of exile for the "Old Ones," his monstrous semi-divine beings of terror and fear who long ago ruled Earth and its inhabitants. In fact, the Hyades is a rather old cluster, and it's known to contain a number of low-luminosity white dwarfs....

The Hyades, so large in apparent extent, is actually one of the nearest of all star clusters, lying at a distance of about 130 light-years. Although the distinctive "V" pattern of the stars suggests a motion to the west, in reality the cluster is moving eastward, toward a point near Betelgeuse. Aldebaran itself is not a member of the cluster, but a much closer star which the cluster stars are passing by in the distance.

According to ancient Greek myth the Hyades were seven sisters, but unlike the seven Pleiades, there was never any agreement as to their names. Hesiod lists them as Koronis, Eudora, Phaeo, Kleea, and Phaesula, but that only adds up to five. Other ancient authors give their names as Dione, Ambrosia, Thyene (or Thyone), Aesula (or Pedile), Polyxo (or Phyto), Koronis, and Eudora, at least getting the number right, but with considerable disagreement over some of the names. In any case, none of these names have ever been applied to particular stars in the cluster (even the stars of the Pleiades received specific names only in relatively modern times).

Whatever their names, the Hyades were at least half-sisters of the Pleiades, since all agree that the titan Atlas was the father of both groups. (He was also the father of the three Hesperides, but they never made it higher into the sky than the colors of sunset.) Most agree that the mother of the Hyades was Aethra, but some name her Pleione, who was also the mother of the Pleiades. In any case all this took place long before Atlas was condemned to carry the vault of heaven upon his shoulders. This punishment he earned for leading the Titans against Zeus when the latter sought to overthrow his father Chronos. The enmity of Zeus toward his uncle Atlas, however, did not extend to his cousins the Hyades. Some say that the Hyades fostered Zeus when he was growing up in hiding. Others add that they later took care of Zeus' son Dionysus when he was a child and in danger, and say that it was for this service that Zeus rewarded them by placing them in the sky as stars.

Others, though — somewhat less convincingly — say that their metamorphosis was a recompense for their extreme grief over the death of their brother, who was named (conveniently enough) Hyas — hence their name of Hyades. Hyas, it seems, was slain one day when he was out hunting, but the entire tale becomes even more dubious when we learn that those who relate this version cannot even agree whether he was killed by a serpent or a wild boar. Supposedly the Hyades cried so much over his body that Zeus transformed them into stars lest they drown the Earth — which they still threaten to do each year when they appear in the sky and their tears bring storms and rains down upon us.

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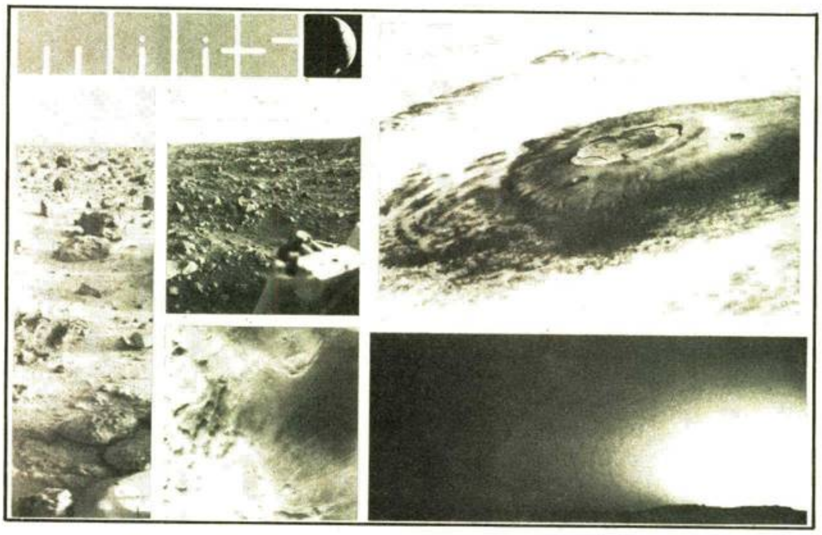

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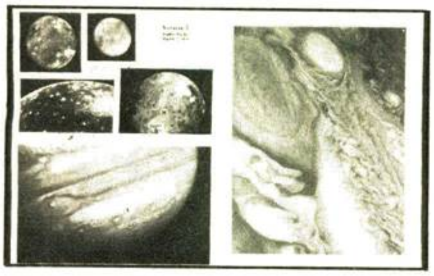

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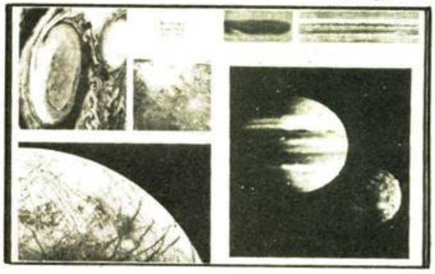

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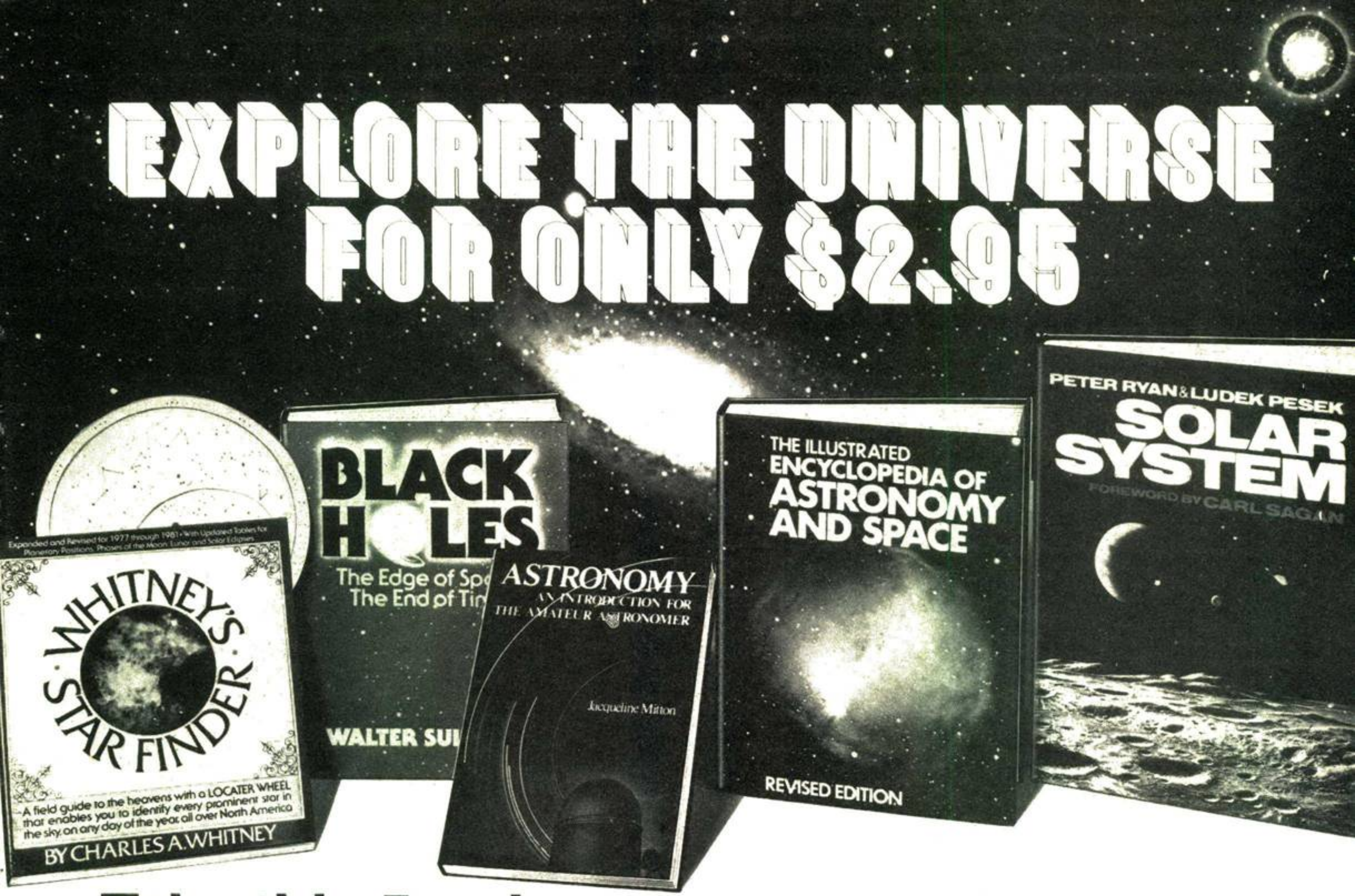
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gazer's gazette

north american solar eclipses: the next 50 years

by
Fred Espenak

In February of 1979, tens of thousands of people from all over the world converged on a 200 by 2,000 mile strip of land from the clammy Pacific Northwest through Manitoba to the icy tundra of Hudson's Bay, parts of North America cursed with miserable weather during that time of year. If not actually snowing, overcast skies and temperatures plunging to a bitter -20° F are common. The goal of these hardy pilgrims was no tropical vacation but a total solar eclipse.

Common sense might well lead you to wonder why so many people spent hundreds of dollars each and put up with many inconveniences to see an eclipse lasting less than three minutes — which would probably be obscured by clouds anyway!

If you *are* wondering, then you've never seen a total solar eclipse — that's for sure. Words, even photographs, can't convey the awesomeness and majesty or the surge of emotion and excitement you experience while witnessing nature's most spectacular phenomenon. Even if you've seen a partial eclipse, there's really no comparison.

Let's imagine that you're standing in the path of the Moon's shadow as it engulfs you. The sky takes on a dark blue color not unlike twilight. A rosy sunrise glow circles the entire horizon: the shadow's edge.

Glancing skyward, you see the brighter stars and planets. But the center of attention is the Sun. Our star has gone away, and replacing it is a hole in the firmament as black as any you've ever seen. You're looking at the unilluminated disk of the Moon silhouetted against the ghostly, beautiful solar corona.

On closer inspection, you notice little red beads scattered around the rim of the Moon's disk and extending out into the corona. These are prominences or clouds of hot gas spewed out from the Sun by violent magnetic storms. Time seems to stand still while you empathize with primitive man who believed his god had been consumed by a demon.

However, the laws of celestial mechanics compel the Moon to continue in its orbit. As you stare spellbound, a sparkle of sunlight appears along one edge of the Moon. It quickly grows, becoming impossibly bright to look at as the Sun's surface reappears. Dazzled eyes turn away while everyone starts wondering when the next eclipse happens.

Eclipse chasing has recently become a very popular sport, spurred in large part by the fortunate coincidence of three total eclipses occurring here in

the 1981 siberian eclipse

On Friday, July 31, 1981, people in Soviet Central Asia and Siberia will see a total solar eclipse. The Moon's shadow first touches down at 2:18 UT at the eastern end of the Black Sea. Heading in a northeastern direction, the umbra quickly crosses the Caucasus Mountains and races over the northern part of the Caspian Sea.

Only a minute after first contact, the shadow enters the Kazakh S.S.R. where the Sun's altitude will be only 10° and totality lasts for 56 seconds. Cutting a 60 mile (95 kilometer) wide path through the steppe, the umbra sweeps into southern Siberia where a number of cities lie in the path.

South of the center line, Belovo sees an eclipse lasting 1 minute 31 seconds with a solar altitude of 35°. Seventeen minutes later, Bratsk will enjoy 1 minute 23 seconds of totality with the Sun 44° above the horizon. Moving due east the shadow skims the northern tip of Lake Baikal at 3:10 UT. Maximum eclipse comes about 35 minutes later to the northwest of the village of Tokur (53° 8′ N, 132° 54′ E) where the Sun will stand 54° high, totality lasting 2 minutes 6 seconds.

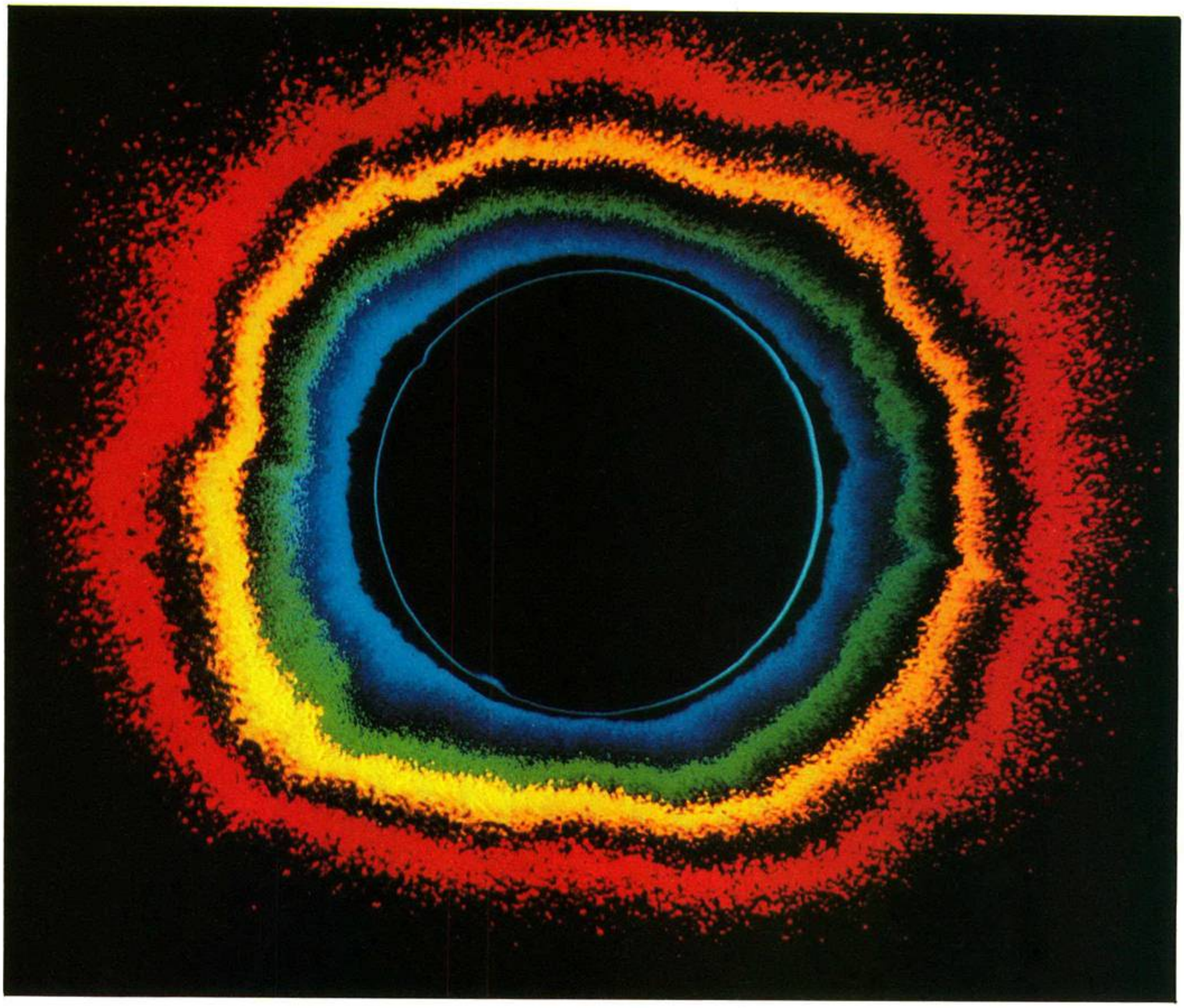
The umbra leaves Asia at 4:02 UT as it quickly crosses the Tatar Strait and Sakhalin Island. Last major landfall is in the Kuril Islands at 4:19 UT. From there the path of totality stretches eastward across the northern Pacific where it crosses the International Date Line at 5:03 UT. Observers in the Hawaiian Islands get a partial eclipse, 90% total, at sunset on July 30th as the umbra passes them by, 500 kilometers to the north. The shadow leaves the Earth at 5:14 UT.

Up to five planets will be visible to the naked eye during totality. Venus will be obvious, 30° east of the Sun at magnitude -3.4. Mercury will be 10° west of it at -1.2 magnitude. Mars will be difficult since it shines at +1.8 and lies 29° west. Jupiter (-1.4 mag.) and Saturn (+1.2) lie 58° to the east and are 2° apart. Siberian observers *will* see them low in the east.

Weather? Kazakhstan and southern Siberia are both favorable, but seasonal average rainfall increases as you go eastward. Clouds are usually cumulus. Daytime temperatures range 75° to 85° F in Kazakhstan and 20° F cooler in eastern Siberia. For maps and local predictions, write the U.S. Naval Observatory, Washington, DC 20390 and ask for Circular #160.

One caution: Make all the plans you like, but remember that observing sites will be assigned by the Soviet government.

Jack Richards took this photo of a partial eclipse in December 1974.



Above: The Sun's corona at the Feb. 1979 eclipse. Photo by the author. Right: The diamond ring by Indian artist Nana Shivalker. Nearby are Venus and Mercury.

the past 10 years as well as cheap air fares. (This last may now be but a fond memory.) If travel becomes expensive, many chasers will have to pass up the more exotic eclipses in favor of ones closer to home. O.K. then, what's in store for us here?

May 30, 1984

On Wednesday, May 30, 1984, Mexico and the southeastern United States will be treated to an annular eclipse of very short duration. In fact, the magnitude of the eclipse comes so close to total that many people hope the corona will be fleetingly visible. The annular phase will last a mere 11 seconds, during which only 0.4% of the Sun's photosphere will peek around the lunar limb.

0.4% visible means the Sun's net apparent magnitude will drop to -20 (as opposed to -27 for the uneclipsed Sun). But this is still 600 times brighter than the Full Moon. It's rather doubtful the corona will appear under these conditions. A very similar eclipse in 1966 obscured an even greater fraction of the Sun's disk, but during the one-second-long annular phase then, no trace of the corona was observed or photographed.

This eclipse has a path of annularity only four miles (7.2 km) wide. But due to small perturbations in the Moon's orbit, the exact position of the path could shift by as much as five miles. Better predictions can be made within six months of the eclipse, but errors of one mile may still exist on eclipse day.

Some of the cities which lie on or near the eclipse path are New Orleans, Louisiana; Montgomery, Alabama; Atlanta, Georgia; Greenville, South Carolina; Charlotte, North Carolina; and Richmond, Virginia. Even though the corona won't be visible, these cities should experience a rather eerie twilight at maximum eclipse. You might catch sight of Venus with the naked eye at magnitude -3.4 only 4° west of the Sun, but anyone watching the eclipse itself will need solar filters.

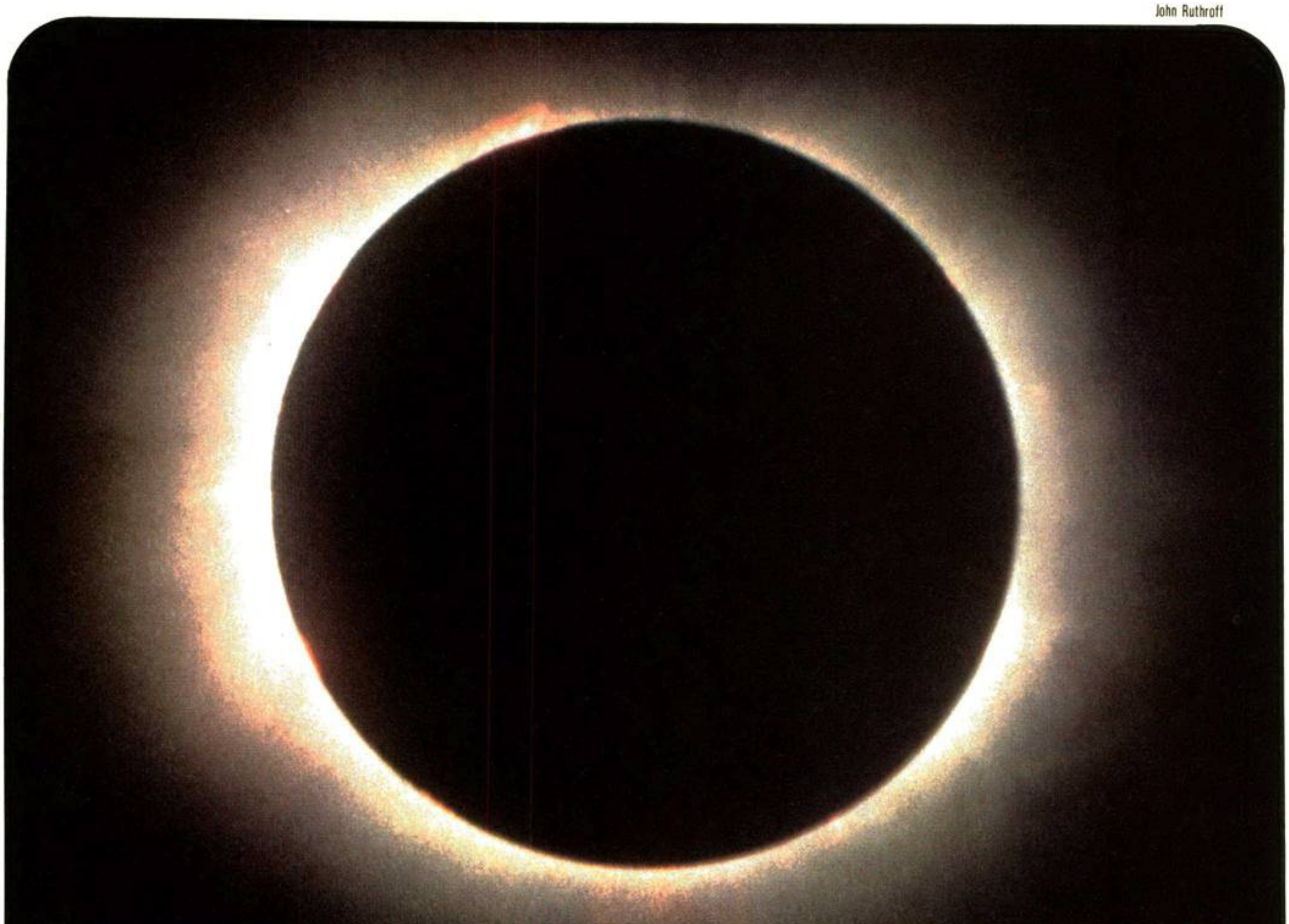
July 11, 1991

North America experiences only one total eclipse during the remainder of the twentieth century, but what an eclipse! On Thursday, July 11, 1991, the Moon's umbra sweeps over the Pacific Ocean, treating the islands of Hawaii and southern Maui to a four-minute total eclipse.

Right on the center line and standing almost 14,000 feet above sea level atop Mauna Kea is one of the world's largest and most sophisticated astronomical observatories. It isn't often that astronomers can make observations of the solar corona using telescopes as large as 3.8 meters (150 inches)!

Moving 2200 miles per hour, the umbra carves a 160-mile-wide path over the eastern Pacific, crossing Baja, California as it enters Mexico. Mexico City lies just north of the center line *where the Sun will stand 80° above the* horizon, and totality lasts an unbelievable 6 minutes 45 seconds.

John Ruthroff



how to make an eclipse

The Moon orbits the Earth once every 29.53 days (New Moon to New Moon). During this period, the Moon swings progressively through its phases from New to Full and back to New again.

At New Moon, it passes between us and the Sun, allowing its cone-shaped shadow (umbra) to sweep across the Earth's surface. If the Moon's orbit lay in the same plane as the Earth's around the Sun, we'd see an eclipse of the Sun every month at New.

Unfortunately, the Moon's orbit is inclined 5° to the Earth's and therefore crosses it only at two points called *nodes*. As seen from the Earth, the Moon crosses the nodes 25 times a year. If New Moon should occur when the Moon is within 10° of a node, the Moon's shadow will touch some part of the Earth producing a total eclipse. Otherwise, the umbra passes north or south of the Earth, maybe producing a partial eclipse somewhere.

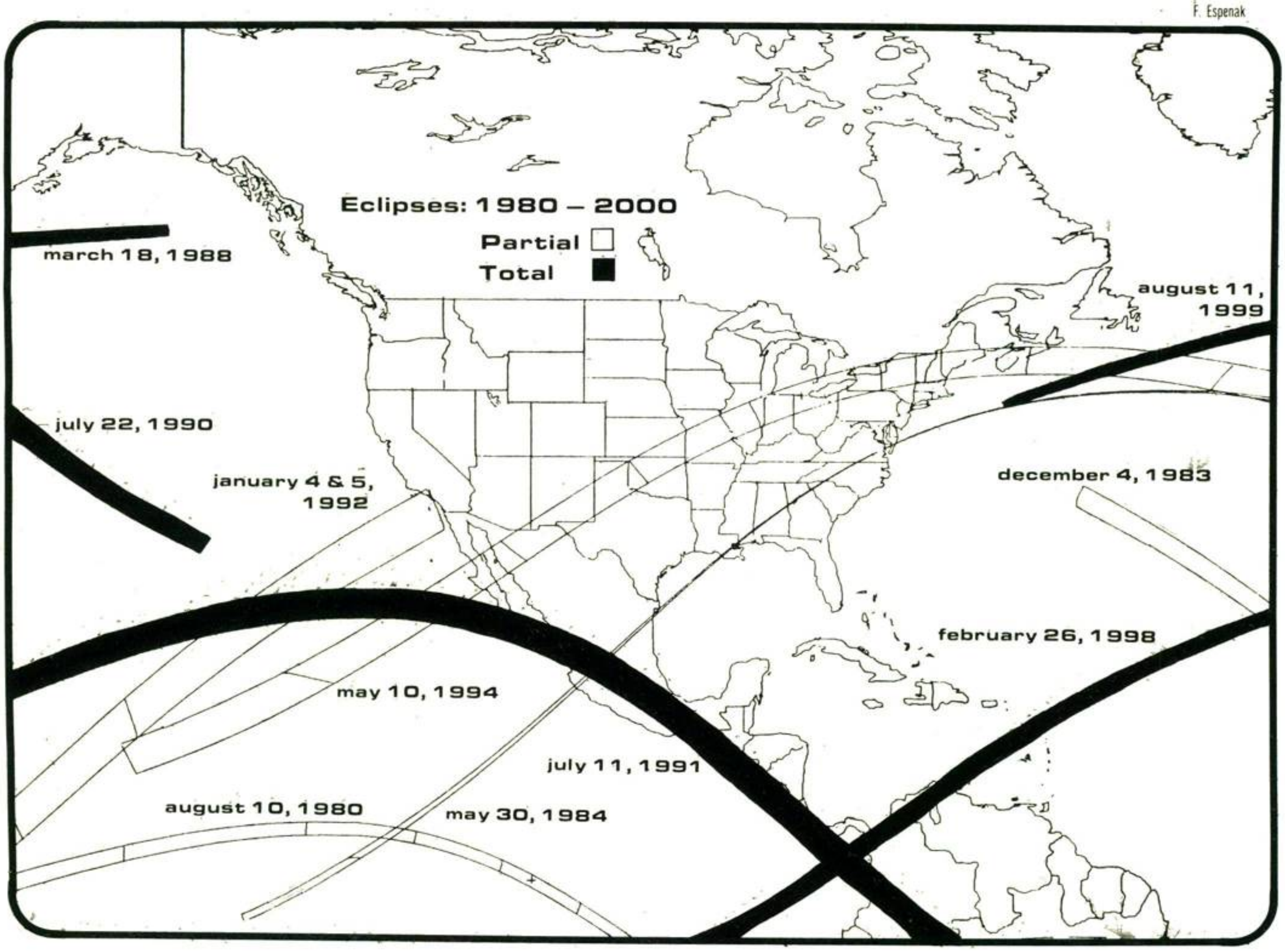
Just to complicate matters, the nodes don't stay fixed in space but slowly drift westward. This precession of the Moon's orbit is not unlike the last motions of a spinning coin which wobbles on its rim before coming to rest. As a result of this precession, the Sun crosses the same node every 347 days. At least two solar eclipses occur each year with as many as five possible. However, only one or two of these may be total and sometimes none of them are.

One of the most remarkable coincidences in the solar system is the fact that the Moon is simultaneously 400 times smaller and 400 times closer to the Earth than the Sun. This means that the Moon and Sun both appear about the same size to us and the Moon's shadow stretches just long enough to reach the Earth's surface. But the Moon's orbit is elliptical and therefore its distance and apparent diameter vary. At apogee, the Moon is farthest from the Earth and appears smaller than the Sun. If an eclipse occurs at this time, the Moon's umbra isn't quite long enough to reach the Earth. A bright ring or annulus of sunlight surrounds the Moon; this is an *annular eclipse*. The corona can't be seen during annular eclipses because it's too faint; the blue sky of scattered sunlight around the Moon's disk is much too bright.

Under rare circumstances, an eclipse may occur when both Moon and Sun have the same angular diameter. This forms a transition stage between total and annular eclipses. It is usually total in the central section of the path and annular at either end. Such an event is possible because the middle of the path is closer to the Moon than the ends due to the curvature of the Earth's surface. An annular/total eclipse will occur on Friday, October 3, 1986 off the southern coast of Iceland. Unfortunately, the U.S. and Canada will only see a partial eclipse.

On average, there are 237 solar eclipses each century. About 36% of these are partial, 32% are annular, 28% are total, and 3% are annular/total eclipses. During each total eclipse, the Moon's umbra draws a narrow corridor across the Earth's surface. It's only along this path of totality that the Sun is completely obscured by the Moon.

The path is usually about 100 miles wide and 10,000 miles long. This amounts to only a small fraction of the Earth's total surface area and consequently any one location sees a total eclipse on the average of once every 360 years.



F. Espenak

East of the Sun in the sky will be Mercury (23°), Jupiter (28°), Mars (39°), and Venus (41°), shining like a string of celestial pearls.

The shadow swings southward along the western coast of Central America where Guatemala City (Guatemala), San Salvador (El Salvador), Managua (Nicaragua), and San Jose (Costa Rica) successively witness the total eclipse. After traveling across Colombia, the umbra leaves the Earth's surface in central Brazil.

This is North America's longest total eclipse during this century and the record won't be surpassed in the next. In addition, excellent weather prospects make this event an absolute *must* for astronomy enthusiasts and laymen alike.

January 5, 1992

Los Angeles and San Diego will observe an annular eclipse just at sunset on Sunday, January 5, 1992. Due to the Sun's low altitude and the strong filtering action of the Earth's atmosphere, the spectacle might even be safe to watch with the naked eye. Outside the annular path, the western third of the U.S. will see a partial eclipse.

May 10, 1994

A fine annular eclipse will be widely visible in the United States on Tuesday, May 10, 1994. After passing over the Pacific Ocean, Baja, California, and Sonora, Mexico, the path of annularity crosses the Arizona, New Mexico, and Texas borders. El Paso stands on the center line where 89% of the Sun's disk will be obscured for almost six minutes.

Traveling northeast, the shadow enters Oklahoma, Kansas, and Missouri where Kansas City and St. Louis respectively border on the northern and southern limits of the path. Springfield, Illinois; Detroit, Michigan; Cleveland, Ohio; Buffalo, New York; Concord, New Hampshire; Portland, Maine; and Halifax, Nova Scotia all lie in the zone of annularity.

Since the Moon's apparent diameter will only be 94% that of the Sun's, many people may not even notice that an eclipse is taking place. The sky will become darker than normal but not alarmingly so. Photographers will notice that sunlit scenes will require three stops greater exposure than usual. In order to observe this eclipse safely, solar filters or projection techniques are necessary.

August 1, 2008

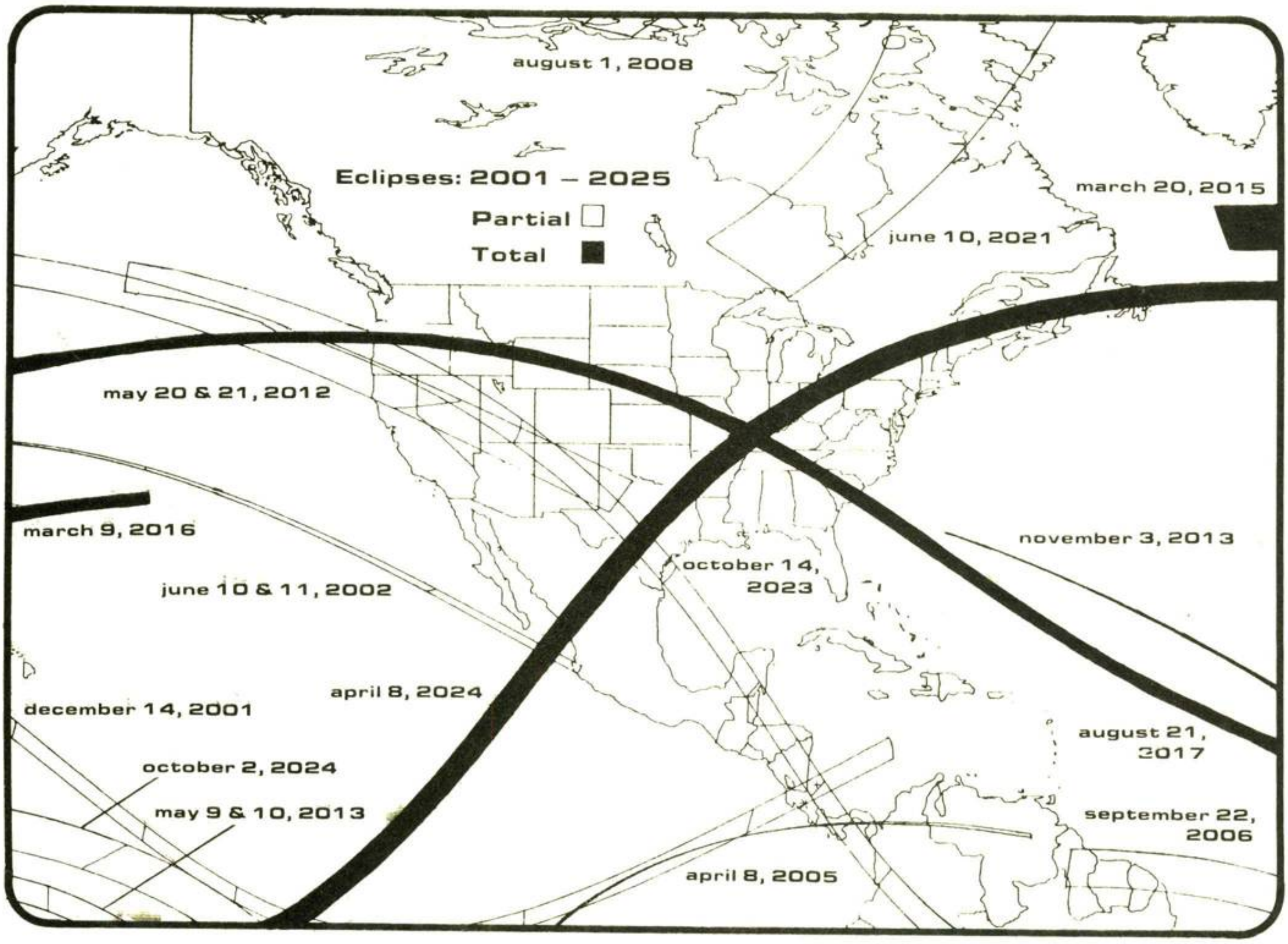
North America's first total eclipse of the 21st century comes on Friday, August 1, 2008. Unfortunately, it'll only be visible from regions north of the Arctic Circle. To make matters worse, the Sun will only be a few degrees above the horizon. Nevertheless, this might make for an interesting end-of-summer trip to the lands of the midnight sun.

May 20, 2012

The western U.S. lies in the path of annularity during the solar eclipse of Sunday, May 20, 2012. The event takes place in the late afternoon on the west coast while Texas observes the eclipse at sunset. Among the cities lying in the path are Eureka, California; Carson City, Nevada; Alberquerque and Santa Fe, New Mexico; and Lubbock, Texas. Some of the National Parks in southern Utah as well as Arizona's Grand Canyon will make unique vantage points as they also witness the 4½-minute annular phase.

August 21, 2017

The long wait for another total eclipse in the continental United States finally ends on Monday, August 21, 2017. On that date, the umbra crosses the country from coast to coast, following a course strongly resembling that of the 1918 eclipse. Although totality lasts but 2½ minutes, the event comes at the height of the vacation season and will undoubtedly be watched by record-breaking numbers of people.



Cities located in the shadow's path include Salem, Oregon; Casper, Wyoming; St. Louis, Missouri; Nashville, Tennessee; and Charleston, South Carolina. Many other cities lie just outside the path: for example, the residents of Portland, Oregon; Lincoln, Nebraska; Kansas City, Missouri; and Atlanta, Georgia need only make a short trip to position themselves in the shadow.

June 10, 2021

On the morning of Thursday, June 10, 2021, Canadians will witness a most remarkable 3½-minute annular eclipse. As seen from western Ontario, the Sun will rise as a ring with only the outer 12% of its disk visible. Due to the Sun's low altitude over the entire path and the fact that the Moon is near apogee, the path spreads an incredible 425 miles wide. It covers eastern Hudson's Bay, Baffin Island, western Greenland, the North Pole, and ends in eastern Siberia. Of course, clouds near the horizon could interfere with seeing this eclipse.

October 14, 2023

A well-placed annular eclipse will be visible from the U.S, Mexico, and Central America on Saturday, October 14, 2023. The 125-mile-wide path travels southeast and covers much of Oregon, Nevada, Utah, New Mexico, and Texas. Santa Fe is near the center line where the annular phase will last almost five minutes. Roswell, New Mexico enjoys the unique distinction of having three annular eclipses (1994, 2012, and 2023) in 29 years, while Corpus Christi will see its first in several centuries.

April 8, 2024

The final eclipse in our 50 year survey is another winner. On Monday, April 8, 2024, the Moon's shadow once again sweeps over North America, bringing with it a precious 4½ minutes to view the awesome solar corona. The umbra will first touch the Earth in the Pacific Ocean and makes no significant landfall along the first half of its path.

It reaches the western shores of Mexico at local noon and quickly engulfs the city of Mazatlan. Twenty minutes later, the shadow will cross into Texas where San Antonio, Waco, and Dallas will be plunged ito darkness. The path continues northeast through Arkansas, where Little Rock will see the totally eclipsed Sun suspended 60° above the horizon.

Cincinnati stands on the southern limit as the umbra crosses Ohio and runs along the U.S./Canadian border. At New Brunswick, the Sun's altitude will have decreased to 30° while totality lasts 3¼ minutes. The path covers the northern half of Prince Edward Island and most of Newfoundland as the umbra travels out into the North Atlantic where it leaves the Earth.

During totality, observers will have a chance to see all five naked-eye planets near the Sun. Venus and Jupiter should easily be visible 15° west and 29° east of the Sun, respectively. Mars and Saturn will form a tight pair 36° west of it but will be more challenging since their apparent magnitudes are both about +1.4. Only 6° east of the Sun, Mercury should prove the most difficult since it will shine at +2.7 magnitude.

Many readers of ASTRONOMY will live long enough to see all the eclipses on our list. If you're 25 years old now, you'll be 70 when the 2024 eclipse occurs. Taking a guess about medical advances in the next half century, it doesn't seem at all unreasonable to expect the average life span to increase to 100 years or perhaps beyond.

Although fifty years may seem a lifetime away, keep in mind that a total eclipse used to be "a once in a lifetime" experience. By planning ahead, you can beat these odds and enjoy each rare opportunity to stand in the shadow of the Moon!

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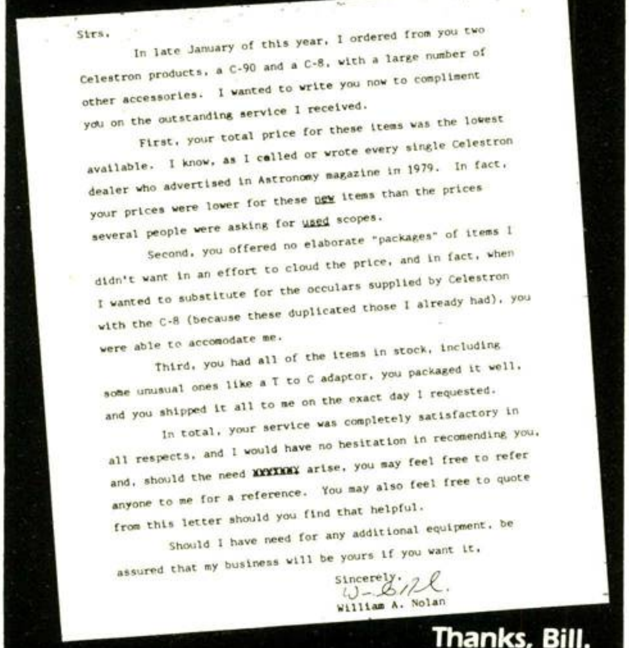

Sirs,

In late January of this year, I ordered from you two Celestron products, a C-90 and a C-8, with a large number of other accessories. I wanted to write you now to compliment you on the outstanding service I received.

First, your total price for these items was the lowest available. I know, as I called or wrote every single Celestron dealer who advertised in Astronomy magazine in 1979. In fact, your prices were lower for these new items than the prices several people were asking for used scopes.

Second, you offered no elaborate "packages" of items I didn't want in an effort to cloud the price, and in fact, when I wanted to substitute for the occulars supplied by Celestron with the C-8 (because these duplicated those I already had), you were able to accomodate me.

Third, you had all of the items in stock, including some unusual ones like a T to C adaptor, you packaged it well, and you shipped it all to me on the exact day I requested.

In total, your service was completely satisfactory in all respects, and I would have no hesitation in recomending you, and, should the need XXXXXX arise, you may feel free to refer anyone to me for a reference. You may also feel free to quote from this letter should you find that helpful.

Should I have need for any additional equipment, be assured that my business will be yours if you want it,

Sincerely,
W-Bill.
William A. Nolan

Thanks, Bill.

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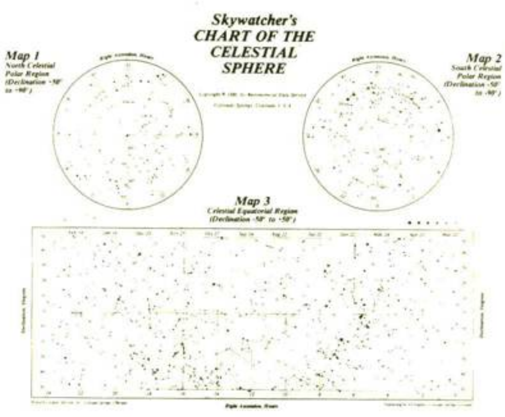
Skywatcher's CHART OF THE CELESTIAL SPHERE
Map 1
North Celestial Polar Region (Declination +50° to +90°)
Map 2
South Celestial Polar Region (Declination -50° to -90°)
Map 3
Celestial Equatorial Region (Declination -50° to +50°)

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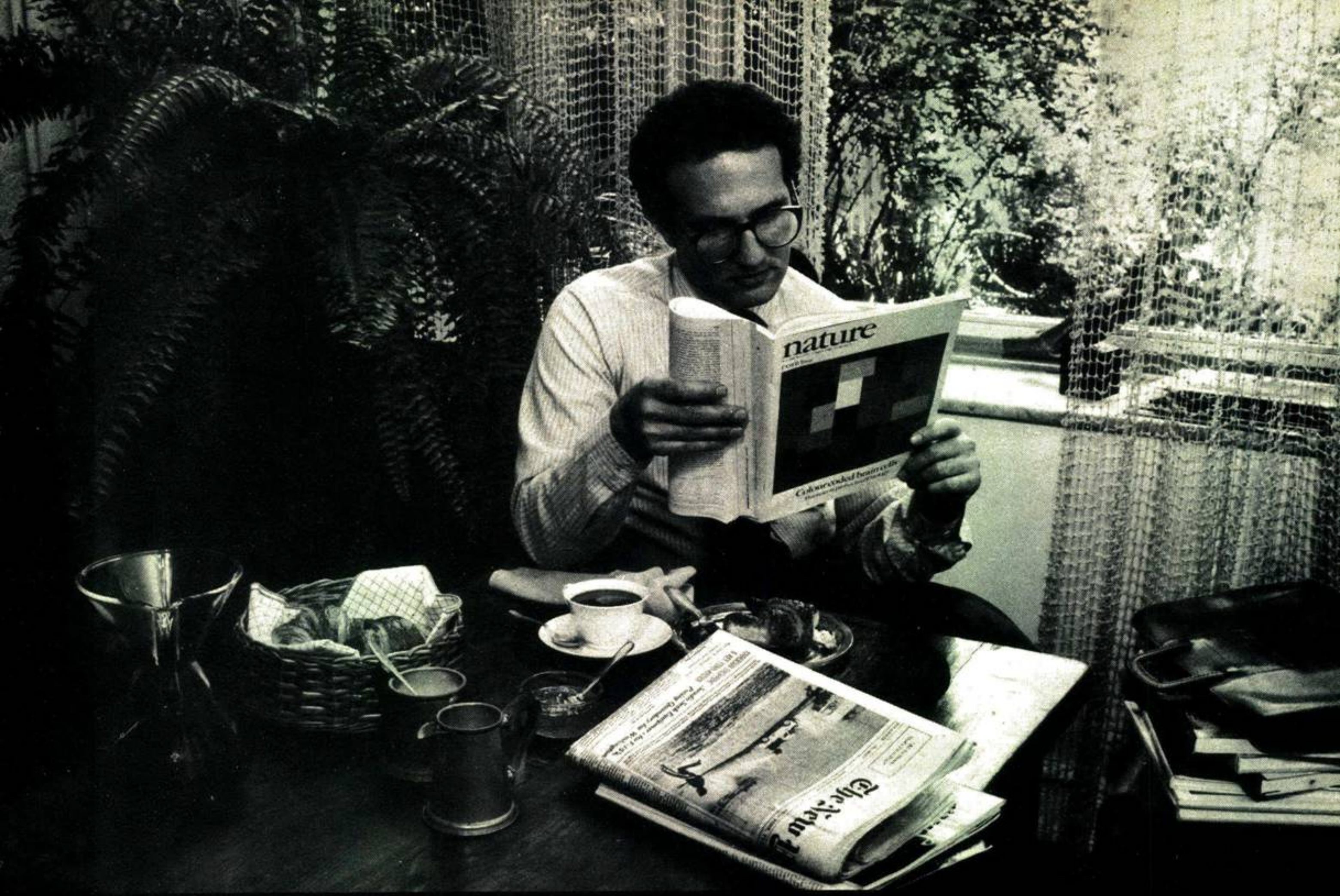

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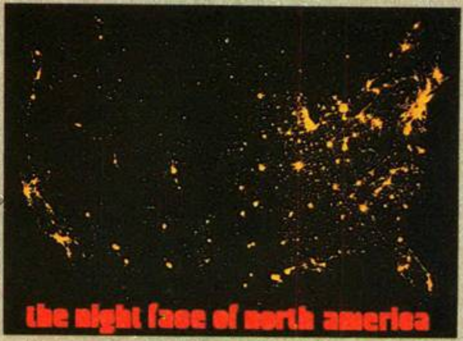
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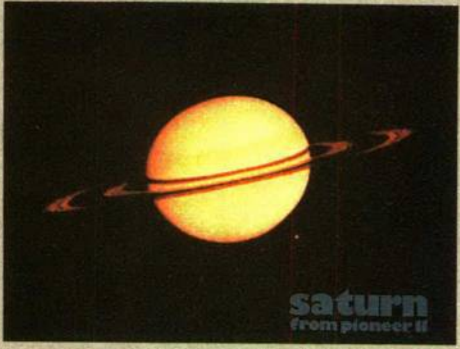
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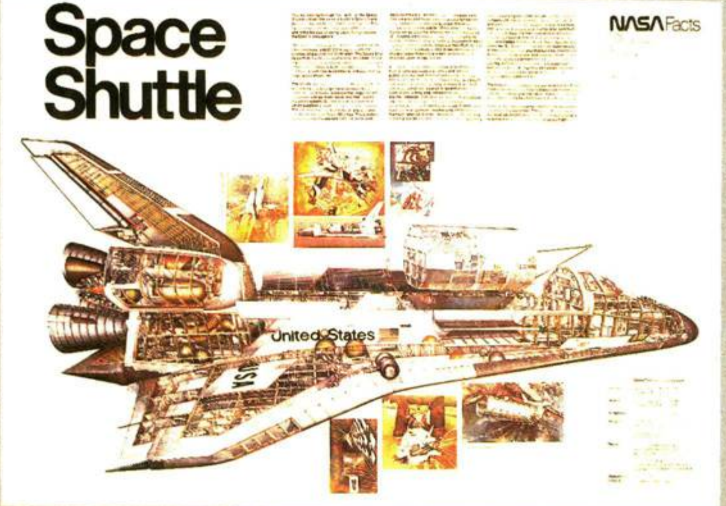
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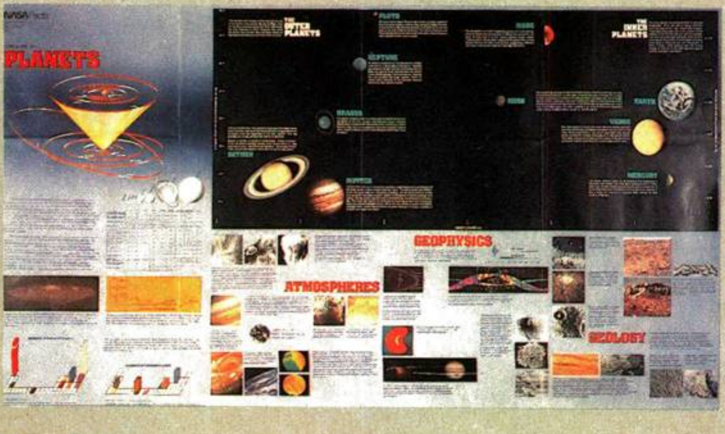
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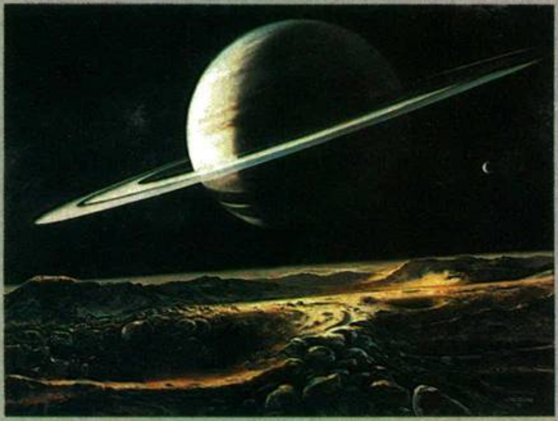

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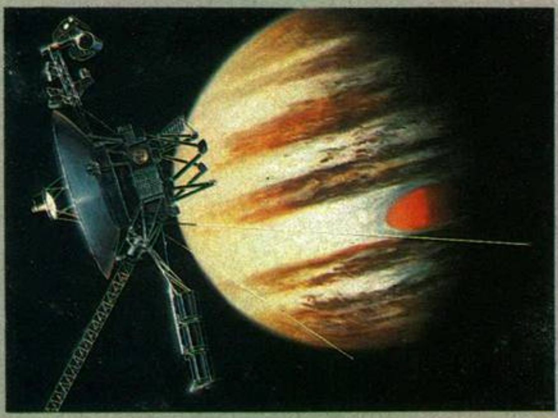

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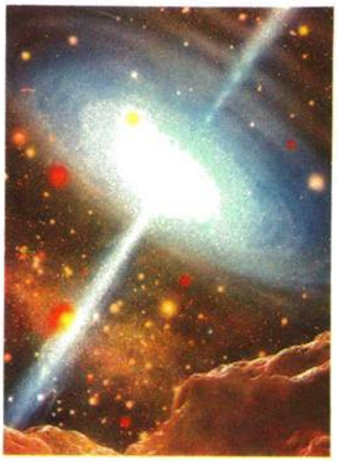

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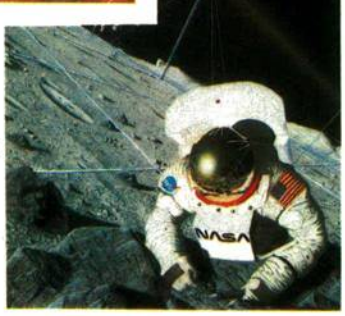

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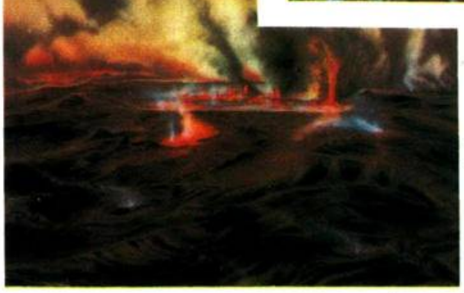

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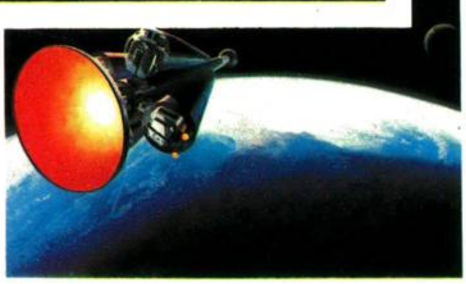

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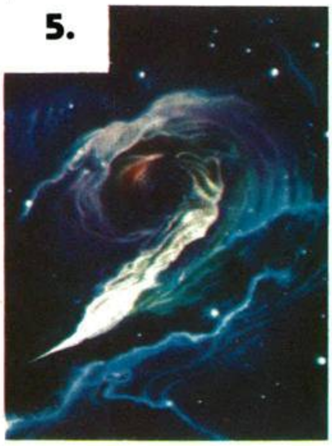

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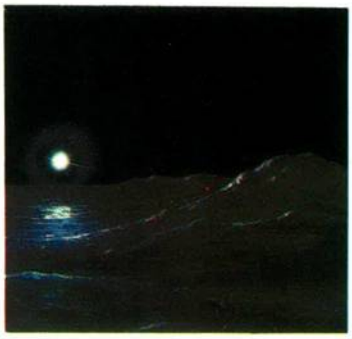

ASTRONOMY IN FOCUS

Voyager 1 & Saturn

Sir / I have learned — semi-officially — that Public Television station KCET in Los Angeles is going to try to cover the Voyager I Saturn flyby in November, using the same format as for the two Jupiter flybys last year: that is, nightly ten-minute updates for a week or so before closest approach, and several hours of live coverage from JPL during closest approach.

Some of the "Jupiter Watch" programming went out over the P.B.S. network, but I have no idea how much of it was actually shown by the other stations around the country.

If anyone wants more detailed information, they should contact:

Jim Mathes
KCET Educational Services
4401 Sunset Blvd.
Los Angeles, CA 90027
(213) 667-9237 (Direct Line)
(213) 666-6500 (KCET Switchboard)

ASTRONOMY readers outside the Greater Los Angeles area should contact their local P.B.S. stations to find out whether or not they are going to carry any of the coverage. Judging from the recent past, P.B.S. is our only hope as far as unmanned space exploration is concerned. If there's no chance of death and/or destruction, the commercial networks aren't interested. On the other hand...during the many hours of "Jupiter Watch" last year there wasn't a single Tang commercial.

Elaine Hampton
Burbank, CA

Star Date

Sir / I would like to inform amateur astronomers in the New York/northern New Jersey area of a new series of mini-lectures on astronomy being presented by a local radio station. FM station WRNW (107.1) is now broadcasting a three-minute spot entitled "Star Date." Put together by the McDonald Observatory (Austin, Texas), Star Date provides the listener with an informative account of what's up in the night sky or what happened that day in astronomical history. The mini-lectures are both succinct and entertaining. Star Date can be heard every night of the week at 11:30 p.m., except on Thursdays, when it is broadcast at 10:30 p.m.

It it because so many of our newspapers and radio stations carry astrological forecasts and other ridiculous items that I urge ASTRONOMY's readers to: 1) write the McDonald Observatory and encourage their efforts in this direction, and 2) inform their local stations about Star Date and urge them to also carry it. Those readers who can tune in Star Date should make every effort to do so and, if they like what they hear, drop WRNW a line telling their program director so. WRNW's address is 55 Woodside Avenue, Briarcliff Manor, White Plains, New York 10510.

Robert T. Ingoglia
Clifton, NJ

Moon Minerals

Sir / The letter of Michael J. Sloboda published in the August 1980 issue writes off the Moon and asteroids as a future source of metals because Sloboda ignores several rich ore deposits that may be formed with or without water.

One example is the Stillwater Complex of Montana. The Stillwater Complex is a layered igneous intrusion. Such rock bodies are formed when liquid rock (magma) begins to slowly cool underground; as the liquid cools, crystals of different minerals are formed and sink to the bottom of the magma chamber, often forming layers of different minerals.

The magma that formed the Stillwater Complex contained several elements that because of the charge or size of the ions did not combine with the common rock-forming minerals. Some of these elements crystallized early and formed distinct layers of ores of copper, chromium (about 90 percent of U.S. reserves of Cr) and platinum group metals. The magma that formed the Stillwater Complex was similiar in composition to the basalts found on the Moon's surface; therefore, below the Moon's regolith may lie similar ores.

A second example of a kind of rich ore deposit that may form on the Moon is the Sudbury Basin. About half the Earth's nickle reserves (plus considerable Cu, Fe, Co, S, Ag, Au, Pt, Pd, Rh, Ir, and Os) are found at Sudbury. The Sudbury Basin and the metals are the result of a meteorite striking the area about 1.7 billion years ago. Perhaps under some of the craters of the Moon are similar deposits.

A final point concerns the composition of asteroids. Some of them may be Fe-Ni bodies rich in the dozen metals we on Earth will be running short of in the next 50 years.

Curtis Hollabaugh
Rock Hill, SC

Occultations

Sir / In the June issue, I read that the Moon would occult Regulus on the evening of June 17th. According to Through the Eyepiece, the occultation should have been visible from where I was watching, but it wasn't. The star never disappeared. It came *very* close, but there was no occultation.

Several friends of mine, farther

south, did see an occultation. What happened? (They'd also like to know where to report their observations.)

Kent Vidrine
Deville, LA

Mr. Vidrine / From your description, you and your friends were straddling the occultation's northern limit line. We're sorry you missed it, but even your friends didn't have "the best seat in the house." Somewhere in between your observing sites was a grazing occultation.

Grazes occur when you are positioned just right to see the star (or planet) pop in and out behind the mountains on the lunar limb. These events are always fascinating but it's difficult to know ahead of time the exact place to be, which naturally adds to the fun. The locations we publish have to be general, because a complete description would take over most of the article.

However you can get detailed predictions, worked out for your location, from the International Occultation Timing Association (IOTA), P.O. Box 596, Tinley Park, IL 60477. Observations (giving latitude, longitude, and altitude of observing site, and times to the nearest 1/5 second) can be sent to IOTA at the above address.

Herschel House

Sir / Last year I was contacted by the Sir William Herschel Society of Bath, England, for donations to help save the house of Sir William Herschel in Bath from destruction. It was from this house that Herschel discovered the planet "Uranus." His great granddaughter (Caroline Herschel), patron of the society, has written to prominent members of the scientific community in the USA.

I have just been informed that, of all the persons contacted in this country, only four (including myself) responded, and then the total donations (excluding my own) were less than $100.

I am appalled by this response, and would like to carry this appeal further to the millions of amateur astronomers in this country.

Although Americans are far removed from the scene in England, nevertheless we should not forget this great man who discovered the first planet of modern times! Although most Americans will never see his house, we owe it to him to perpetuate his memory.

I hope you feel moved to help in this endeavor.

Send donations to:

Dr. L. T. Hilliard
290 High Street
Batheaston, Bath
BA1 7RA England.

Bernard Hobdell
St. Petersburg, FL

How to Find 'Em

Sir / I have just finished Earle F. Dodds' helpful article on "How to Find 'Em" in the August 1980 issue. Our backyards must have similar challenging characteristics and I think I can understand why he finds himself locked in there for most of observing. I obtained my first scope in 1925.

Here is *my* gimmick: I purchased a plastic circle template, obtainable in any stationery store, containing holes from 1/16th to 1½ inches in diameter. Using my 40 and 16 mm eyepieces in my four-inch Maksutov, I found two pairs of stars that would be 180° apart at the extreme periphery of each eyepiece viewing field.

Using the field and deluxe editions of the *Atlas of the Heavens* and the *Atlases Borealis* and *Eclipticalis*, I found those holes in the template that just encompassed the chosen pairs of stars for each atlas and power. Using hobby paints to color the edges of the appropriate hole enables me to tell which atlases they are intended for.

To find the position of any elusive object, I locate on the atlas a nearby star that can be easily indentified in the finder. From there I move the proper template hole so many fields north-south or east-west. This is duplicated in the scope using stars in the pathway for confirmation. Having reached my desired location, I stand there hooded, shrouded, etc. muttering softly until averted vision comes to my rescue.

Theodore Pollock
Passaic, NJ

Ooops

In the October In Focus, we omitted *Kronos* Editor-in-Chief Lewis M. Greenberg's title and affiliation:

Professor of Art History
Moore College of Art
Philadelphia, PA.

The equations for resolution in "What's My f/Ratio" (October issue, page 50) should have been printed as:

R = 4.5/D (when D is in inches)
R = 115/D (when D is in millimeters).

behind the scenes

the best astro-photo award

What do Jack Child, Lee Coombs, Craig McCaw, Jean Dragesco, Josef Habina, Jack Newton, and Robert Flory have in common? Hint: They're all astrophotographers. Got it? Yes, they've all won ASTRONOMY's "Best Astro-Photo" award.

Each month since May, after sorting and evaluating many fine photo submissions, we have chosen one picture that is in a class by itself. We run that picture in a place of honor (facing the opening page of Through the Eyepiece), and we award the winner a prize of $100.00.

We feel that each of these images, and each of these observers, has reached a pinnacle of achievement: capturing some of the elusive celestial beauty what makes astronomy such sublime adventure.

The winner is sometimes a color picture; other times it's a black and white. While having a big telescope is advantageous, equipment doesn't make a winner. One winner used a 6", one an 8", another a 10", and this month's used no telescope at all!

Take the time to look at each a little longer, and appreciate with us that extra "something" which makes a beautful picture more than just beautiful. And naturally, if you're doing astrophotos yourself, send them in. Every submission is an entry in the contest.

This month, with the holiday season close upon us, ASTRONOMY has more pages — 114 — than ever before. We're pleased that Steve Walther's dream, a beautiful and informative magazine that brings the universe to all its readers, is still growing vigorously in readership and size.

Sincerely,

Richard Berry

Richard Berry

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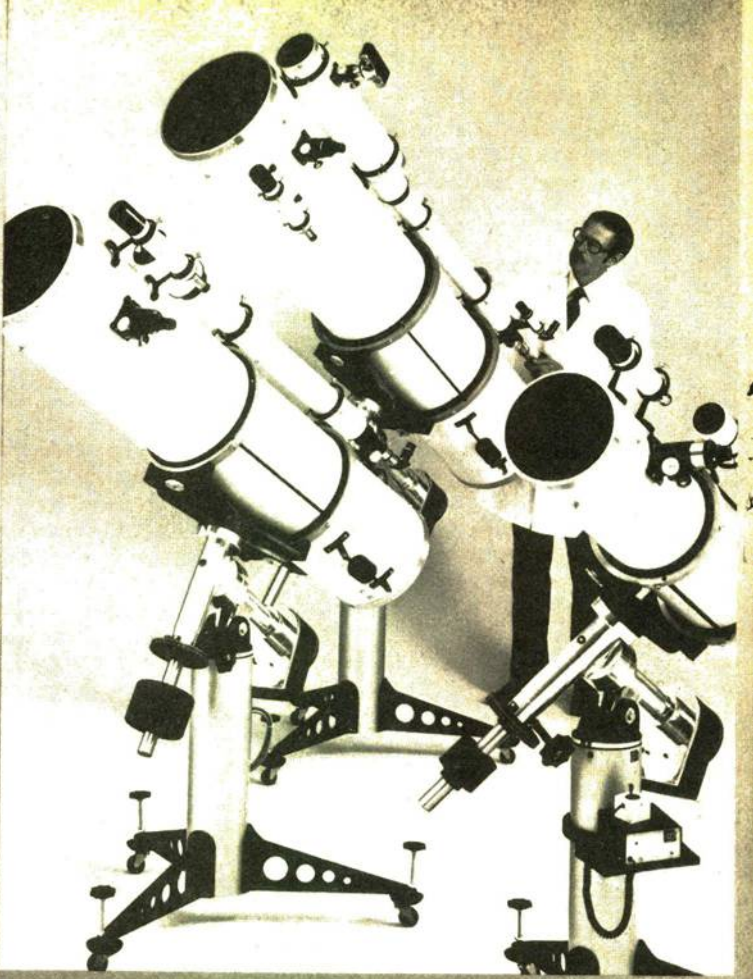
Designed by Meade engineers and in continuous production at our Costa Mesa facility, these telescopes possess capabilities generally obtainable only at much higher prices — and they are the only telescopes available which use exclusively the quality Meade components known throughout the astronomical world.



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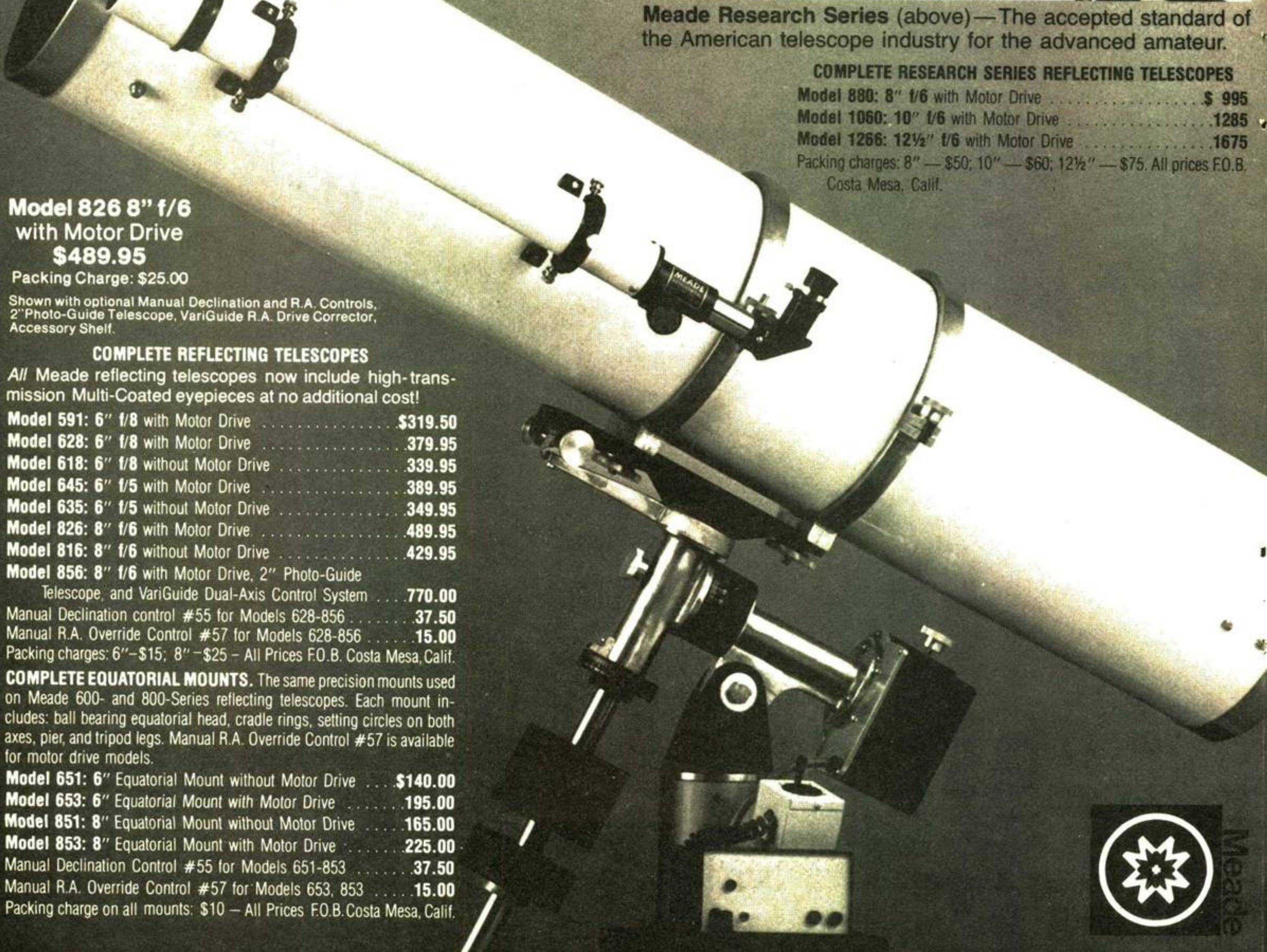

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Model 826: 8″ f/6 with Motor Drive	**489.95**
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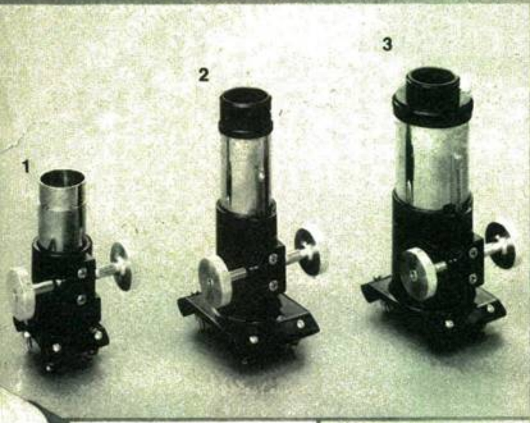

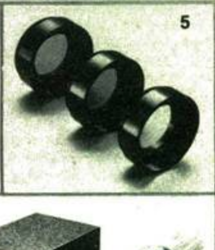

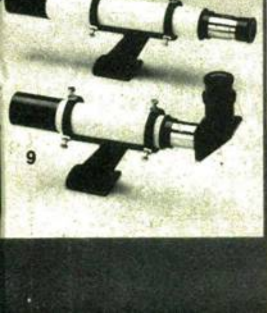

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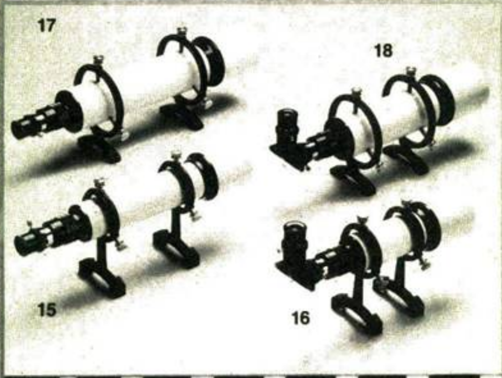

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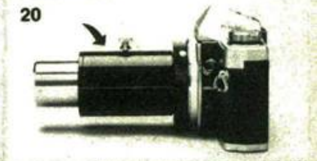

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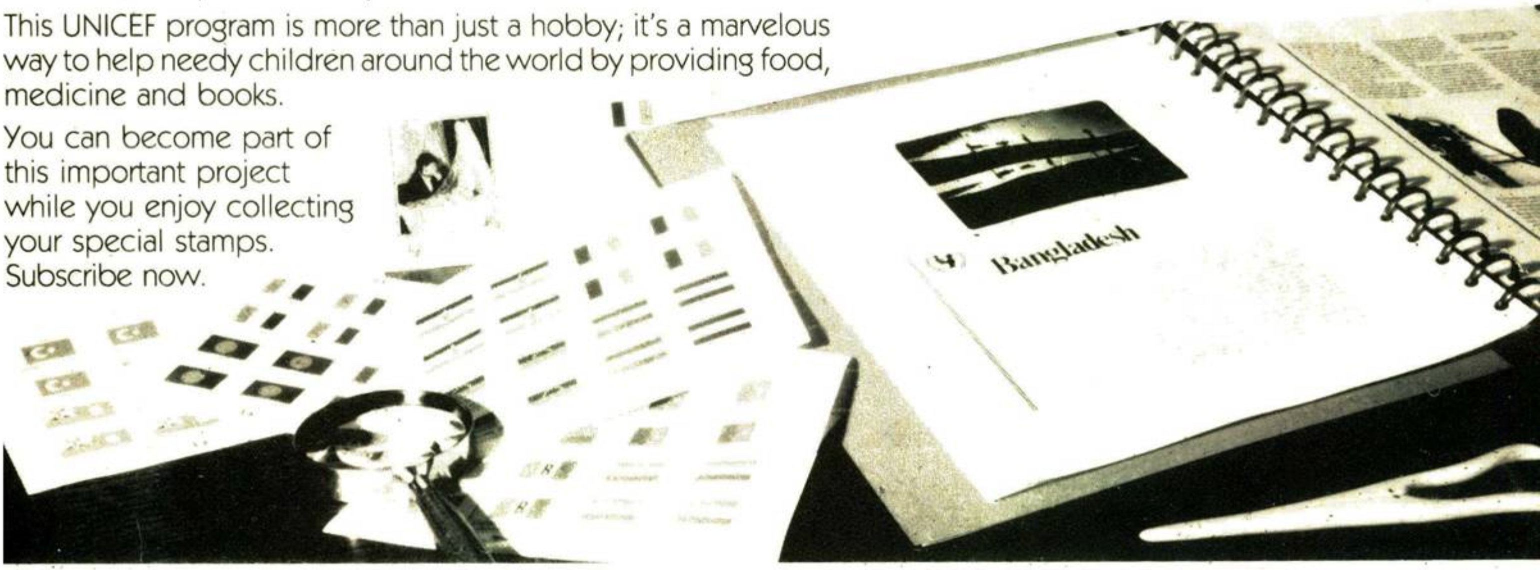

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equipment atlas

equipment for guiding your astrophotos

by Walter E. Hamler

If you're like me and most other telescope owners, the time comes when you want to photograph at least some of the objects you have viewed through an eyepiece. Most of us start off by simply piggybacking our camera and lens on the telescope, and exposing while the telescope drive is running.

Fifteen to 20-minute exposures work well and with the right film, filters, and dark skies, the results will be very pretty. Why? Any drive inaccuracy or drifting due to polar misalignment usually gets lost in the bloopy images and small image scale you always have with short focal length lenses.

But when you want a bigger image on the film, you must increase the focal length of the lens and this means you can no longer simply tack the camera onto the telescope, turn it on, and wait for the glorious photos. To keep star images nice and round and details crisp, you have to monitor the movement of the telescope. In other words, you have to "guide" the photograph, using a second instrument called a *guidescope*.

We'll get to some guidescope specifics in a minute, but first let's see just how precise your guiding has to be. It turns out that knowing how much "slop" you can tolerate determines everything. Since you have to detect image movement with the guidescope before it becomes noticeable on the film, you need to know when an image will become noticeably out-of-round in your photo.

There are two approaches to this. You can determine either the "eyeball" resolution or the smallest image the total system can produce. Let's look at both ways and see how they compare.

Do It By the Numbers

If we assume the average eye can resolve one minute of arc, then it cannot discern the difference between a round star image and one smeared out 0.003 inch if viewed from a distance of 10 inches. If you were to make a 10x print of a star field, then no star's image on the negative could trail more than 0.003/10 = 0.0003 inch if you wanted that star to look round.

Taking this as the goal, the following formula will show the maximum error you can allow:

$$S = 619/(F \times E)$$

where S is the error ("slop") in seconds of arc, F is the focal length in inches, and E is the enlargement. With a 40-inch focal length telescope and a 10x enlargement, you get a maximum guide error of 1.6 seconds of arc. In other words, keep the guide star within a circle having a diameter of 1.6 arc-seconds.

Trifid Nebula, M-20 W. Hamler

This sounds difficult, but fortunately, only rather faint stars produce the very smallest images where guide errors are most noticeable. Bright stars make large round images on the film because their light scatters sideways through the emulsion. Because the formula above ignores light scattering, its results are unrealistically stringent.

A fine-grain film can record images as small as two to three microns (0.0001 inch to 0.00015 inch). However, the coarse-grain spectroscopic films commonly used give images eight to 10 times larger, or about 0.001 inch on average. The formula then becomes:

$$S = 206/F$$

where S is the error in seconds of arc and F is the focal length in inches. With a 40-inch focal length, this indicates that an error of five arc-seconds will show. Smaller errors will be lost due to film grain.

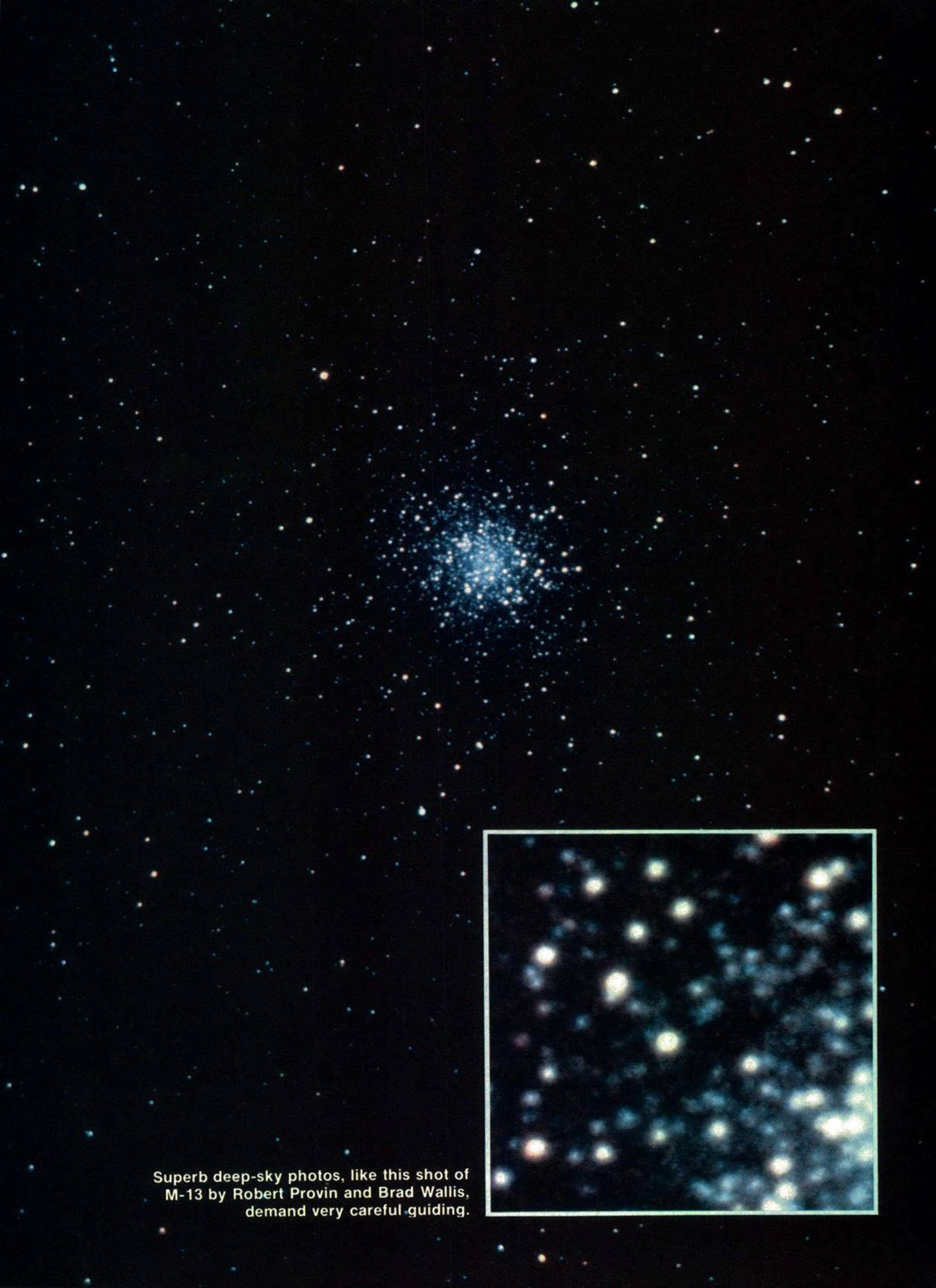
If you use fine-grain films, you'll have to decide by trial and error how closely the strictures of the first formula must be followed. A certain amount of drift outside the limit is acceptable so long as the duration and distance aren't excessive and the guide star spends the greatest percentage of the time centered.

The Guidescope

Guidescopes typically have apertures less than that of the photographic telescope. But whatever the size, they should have a focal length equal to or greater than the primary's focal length, without using any focal extenders or Barlow lenses. (Conflicting with this is another valid principle that calls for a relatively light and compact guidescope, for weight and balance reasons!) In short, you're looking for a small aperture telescope of a high focal ratio, typically f/12 to f/15, or even f/20.

A second rule of thumb asks that the guidescope deliver a minimum magnification of 5x per inch of the primary's focal length. For example, with a 40-inch focal length primary, you'll need a minimum of 5 x 40 = 200x. And this means clean, usable, undistorted magnification, preferably with at least a moderately wide apparent field.

So much for theory; let's look now at the different types of guidescopes and make some general recommendations.



Superb deep-sky photos, like this shot of M-13 by Robert Provin and Brad Wallis, demand very careful guiding.

By the above criteria, it sounds as if the commonly available 60 mm to 80 mm refractor would make a fine guidescope for the average 6 to 8-inch telescope of a relatively fast Newtonian design, say f/4 to f/6. A closer look shows things aren't so simple.

Refractors make nice guidescopes because they are solidly constructed and hold their optical alignment well. Another advantage is their closed-tube design which reduces bothersome air currents and guide star scintillation problems.

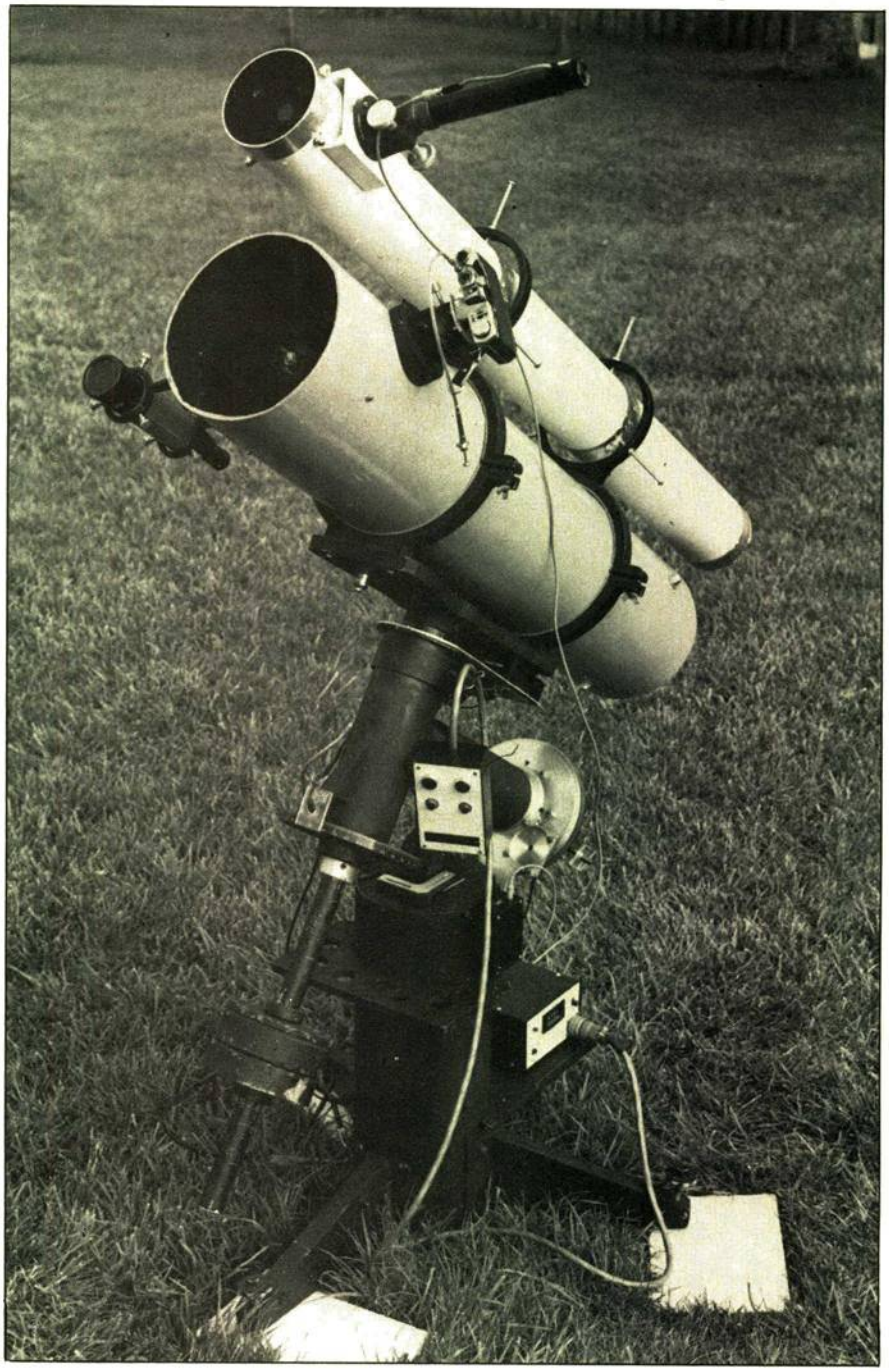
But a big disadvantage I see with refractors on Newtonians comes when you are photographing around the zenith, a common occurrence. Then the guiding eyepiece is 'way at the back end of the tube, down near the ground somewhere. Trying to guide like that is very tiring and moreover places the eyepiece far away from the camera.

Therefore I use a 4¼-inch f/13 Newtonian guidescope on my 8-inch f/5 Newtonian. This puts the guiding eyepiece conveniently next to the camera and controls. I can frame an object in the camera and find a suitable guide star in one easy operation.

Another advantage of a Newtonian guidescope is its reasonable cost. You can either buy one as a finished unit or assemble it from purchased parts — even make one from scratch! Just be sure that all the components fit together rigidly or you'll have flexure problems.

Of course, Newtonians aren't the whole story. Many astrophotographers use other types of telescopes, such as Cassegrains and refractors. But if you're using a refractor or a Cassegrain telescope, finding a satisfactory guidescope becomes more complicated. Unless the mounting was specifically designed and built for a second instrument of much the same length and bulk as the primary, structural problems will arise to which there's no all-purpose answer. This holds especially true for refractors.

Rather than redesigning, rebuilding, or otherwise modifying the existing mount, you may end up settling for a guidescope that violates some of the rules of thumb mentioned earlier. It might have a shorter focal length than the primary (but make up for it with focal extenders or Barlows), or it could be of a different type (a refractor on a Cassegrain primary, for example). The difficulty here is that many compound-type telescopes such as Cassegrains have an f/10 to f/15 focal range and for a guidescope you'll be hunting one having a higher f/ratio, such as f/20 or more, and those are uncommon.



With *any* guidescope, secure attachment is very important. Use substantial ring mounts with large adjusting screws. But don't use rings that are too large; they'll probably wobble. You only need to move the guidescope in the rings a small amount to choose a suitable star.

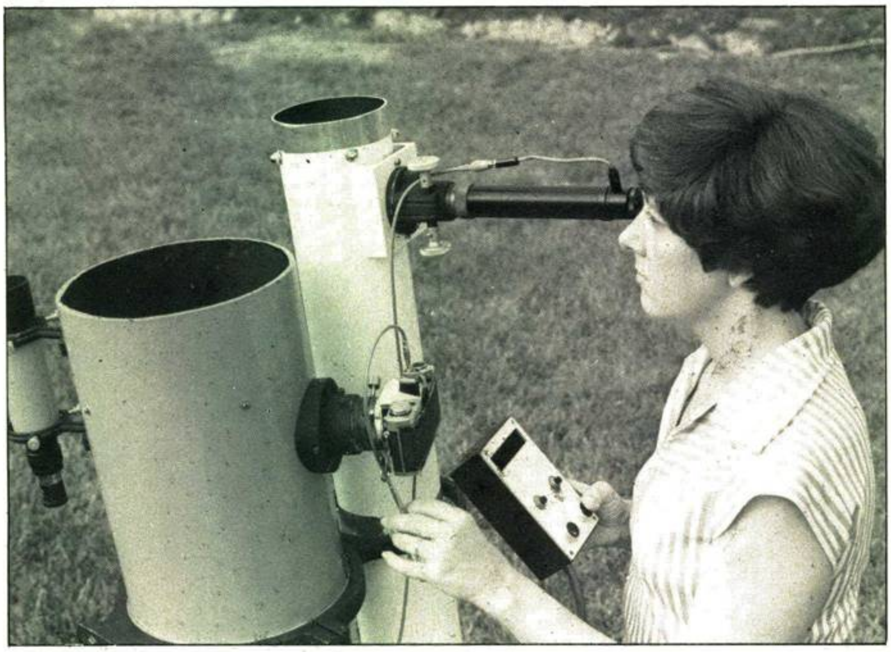
When you're out in the field, check all nuts, bolts, and fasteners to make sure each is tight and rigid prior to starting your exposure. Nothing's more frustrating than discovering something loose after the exposure or, worse yet, after an entire night's shooting. Flexure or movement of a component is the single greatest problem contributing to poor quality astrophotos.

Off-Axis Guiders

The most common solution to guidescope miseries is the "off-axis guider," an optical device that picks up a small amount of light from the edge of the primary's field of view. By using a Barlow lens and a cross-hair reticle in the eyepiece, you can guide with the same optics that are taking the picture.

An off-axis guider is very common on large professional telescopes, working well with Cassegrain-focus instruments. Even some astrophotographers with Newtonians, especially large aperture (12-inch or more) ones, have installed these useful guiders.

Off-axis guiders totally eliminate differential flexure, a frequent defect



Left: 8" f/5 Newtonian with its 4¼" f/13 guidescope, illuminated eyepiece, and drive corrector. Above: all the controls at the eyepiece. Photos by W. Hamler.

of inadequately mounted separate guidescopes. Their main disadvantage lies in finding a suitable guide star in the same field as the subject. With large apertures (which reach down to fainter magnitudes), it's less important, but with a typical 6, 8 or 10-incher, finding a suitable guide star can be frustrating indeed.

Guiding Eyepieces

In a real pinch, an ordinary eyepiece can serve in a guidescope, but even at relatively high magnifications, it's not easy to detect small movements of a star unless you have a reference point. This is why guiding calls for a special eyepiece with a built-in cross hair or reticle. When the guide star lies at the junction of the cross hairs, you can instantly detect any movement and see the effect of your corrections.

For wide-field (noncritical) photography, a simple unilluminated cross hair suffices. Find a bright star and throw its image slightly out of focus; the field will light up enough so you can see the cross hairs in silhouette. Place them to bisect the out-of-focus star disk, and then align them with right ascension and declination to make guiding corrections easy.

But often you'll be guiding on faint stars, what then? This calls for an eyepiece equipped with an illuminated reticle, colored red to save night vision. There are several available commercially; check the ads in ASTRONOMY. (Or you can construct your own; *All About Telescopes* by Sam Brown is one of several good sources telling how — try your library or buy a copy from Edmund Scientific.)

Naturally, plain cross hairs aren't the only kind of reticle. The kind I prefer has dual cross hairs making a central square. By varying the magnification (via Barlow), the angle on the sky the central square represents can be made to fit the guiding tolerance I've worked out by the formula.

I find keeping the star centered in the box easy and very helpful for ensuring good results. With my equipment, a 3x Barlow and a 12 mm eyepiece give a power of 350x. Each side of the square is then approximately 10 arc-seconds long. By keeping the star centered in the square and confining any drift to within this area, I can easily guide to a five arc-second tolerance.

Drive Correctors

With few exceptions, telescope drives have a small synchronous motor and reduction gears. By varying the frequency of the AC current supplied to the motor, you can vary its speed to correct errors in right ascension tracking. In addition, many commercial variable frequency power supplies (drive correctors) also convert your automobile's 12 VDC to 110 VAC. This is really handy since you often do astrophotography at remote locations, far from an AC power supply.

In recent years, the proliferation of solid-state electronics has made drive correctors rather commonplace. Not only can you buy one "off the shelf," but do-it-yourselfers have an array of plans, schematics, and kits readily available. Apart from cost savings, kits offer the chance to adapt and customize your telescope, mounting, and drive into a neat package.

With a multiplicity of drive correctors comes the question of how fancy a one to buy. Some claim very high accuracy and stability — better than one part in 10,000 (0.01%). Coupled to a telescope that is permanently mounted and "finely tuned" (i.e., has precise polar alignment, accurate balance, good drive, no flexure problems), one of these will certainly live up to its specs. But with the typical portable instrument, the accuracy of a drive corrector isn't all that critical — remember, you're going to have to guide and make corrections constantly, anyway.

Whatever the degree of sophistication, a major consideration is the output power of the unit. I recommend an output of at least eight watts per drive motor used, and more if you use unusually large ones. For instance, the Hurst PC-DA type motor (often used as a declination drive) works very well, but draws a tremendous surge current when you activate it because it has a magnetic clutch. If your drive corrector has insufficient power, you could blow some fuses or worse, damage the circuitry.

You can move the telescope in declination by either of two methods. One uses slow-motion gears turned by hand; the other approach has reduction gears and a synchronous motor driven by a variable frequency power supply — just like the right ascension drive.

Clearly the smoother of the two systems, all else being equal, is the electric one — it keeps those ham fingers off the telescope! But it *is* expensive, and that's why some people prefer a hand-powered declination "drive."

If you're a beginner, by all means use hand power to start with for declination slow-motion. With practice, most people become pretty adept at making the adjustments without shaking the scope too much. You will, too — and it'll give you time to think over whether you want the extra expense of electrical power.

The best advice on equipment says: Know what you need, choose your equipment wisely, and don't be afraid to start small. One piece of good manageable equipment used to its utmost will provide more fun and satisfying results than a backyard full of overambitious equipment that languishes unused.

Walter Hamler began taking sky photographs in 1974. An article of his on equipment for astrophotography appeared in TELESCOPE MAKING #7.

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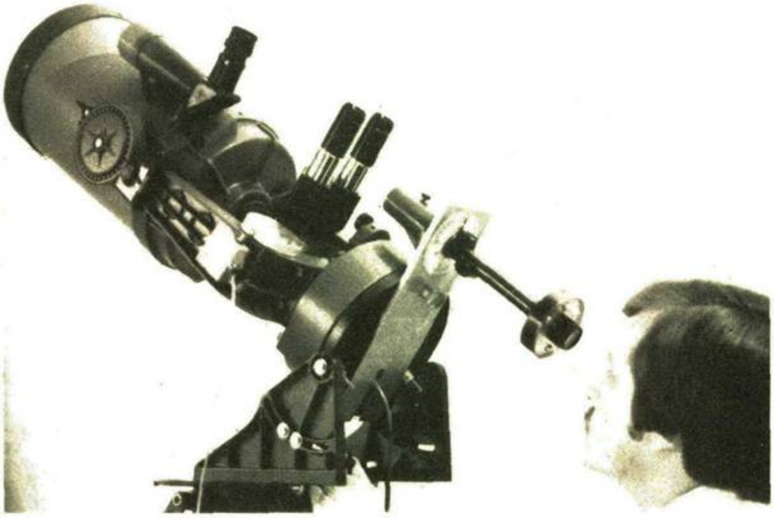

Kerry D. Martin shown aligning his Celestron 8 with OUR Precision Polar Axis Finder

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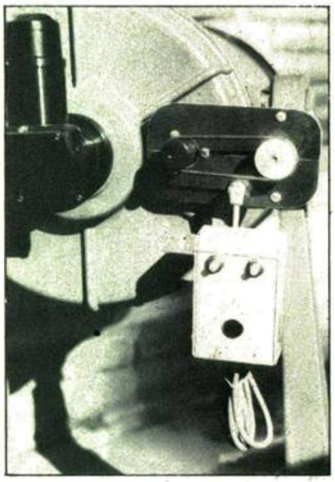

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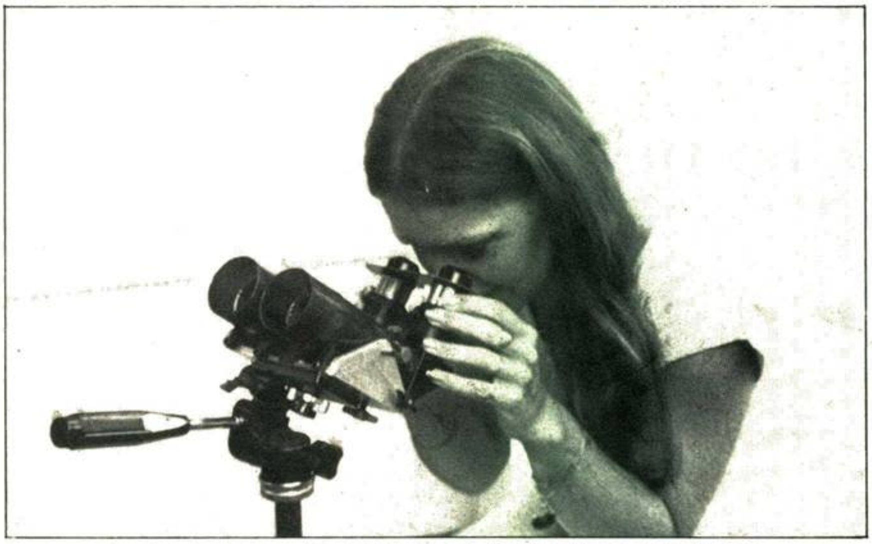

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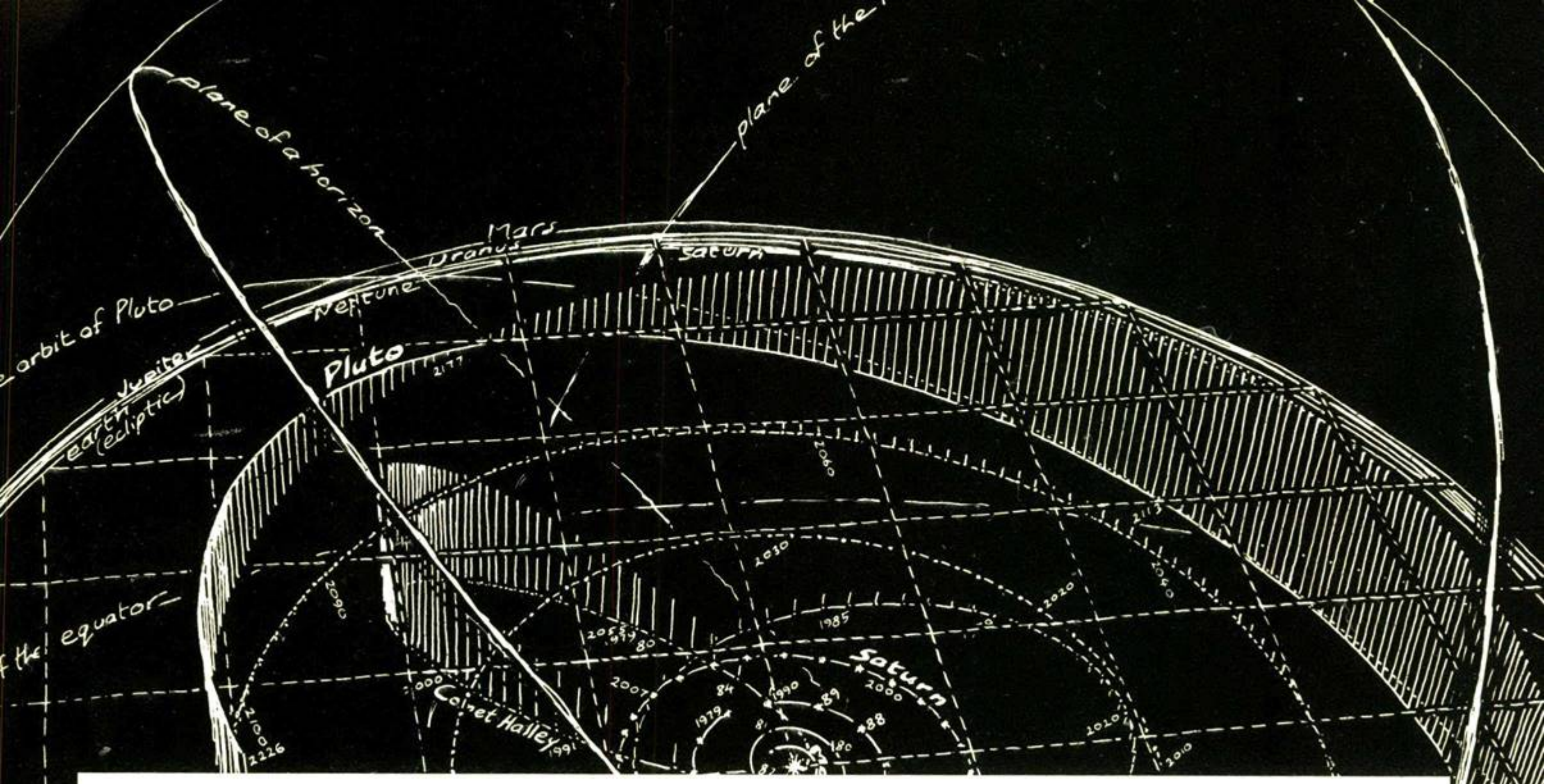

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—George Lovi in ***Sky and Telescope***

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From: **Astronomical Calendar, c/o Dept. of Physics, Furman University, Greenville, S.C. 29613, U.S.A.**
Checks payable to **'Astronomical Calendar'**, please.

processing your astronegatives

photography in astronomy

You've finally put your darkroom together. Everything's all prepared and ready to go. Now for that scary, exhilarating moment — souping your first roll of film.

First, collect the supplies and equipment. You need a roll of film, developing tank (and reel), graduate, thermometer, funnel, chemicals (developer, stop bath, fixer, and wetting agent) and their storage bottles, 3 one quart wide-mouth jars, a bottle opener, scissors, and clothespins.

Nervous? Sweaty-palmed? Perhaps it's the prospect of wrestling in the dark with a 5-foot celluloid serpent. Or maybe you're afraid that when you've subdued the film-monster you won't be able to find some vital piece of equipment — like the tank cover — which condemns you, of course, to spending the rest of your life in there with the lights out.

Well, there *are* tricky aspects to loading a film tank — even in daylight — and doing it in total darkness is difficulty cubed until you become experienced.

But you don't have to have "fingerprint nebulae" all over your first few rolls! Here's what you do:

Practice Makes...

The operation that frightens most beginners and leads to damaged negatives is taking the film from its cassette and loading it into the tank. To increase your confidence, try it ahead of time in daylight using a dummy roll of film. Go out and buy a 36-exposure roll — get the cheapest you can.

With the lights on and the dummy roll in hand, pick up the bottle opener and pry off the bottom of the film cassette. Remove the spindle with the film coiled around it and unroll the film, letting your fingers touch only the edges.

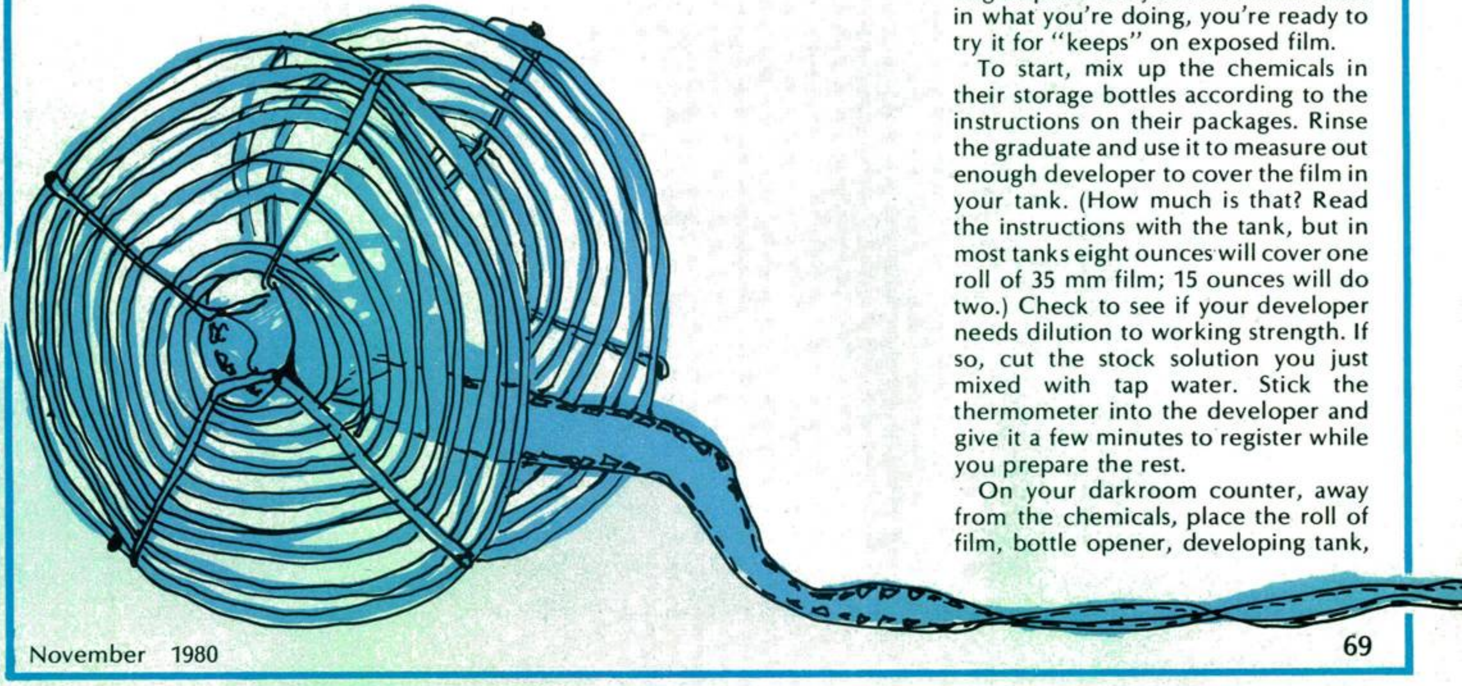
When you reach the inner end of the coil, where the film is taped to the spindle, detach it by unfastening the tape. (The little glow you'll see later when you peel the tape in the dark is static electricity and won't fog any film that isn't where the tape touches.) Your fingers can cheat a bit when unsticking the tape, as long as they touch only the very end of the film.

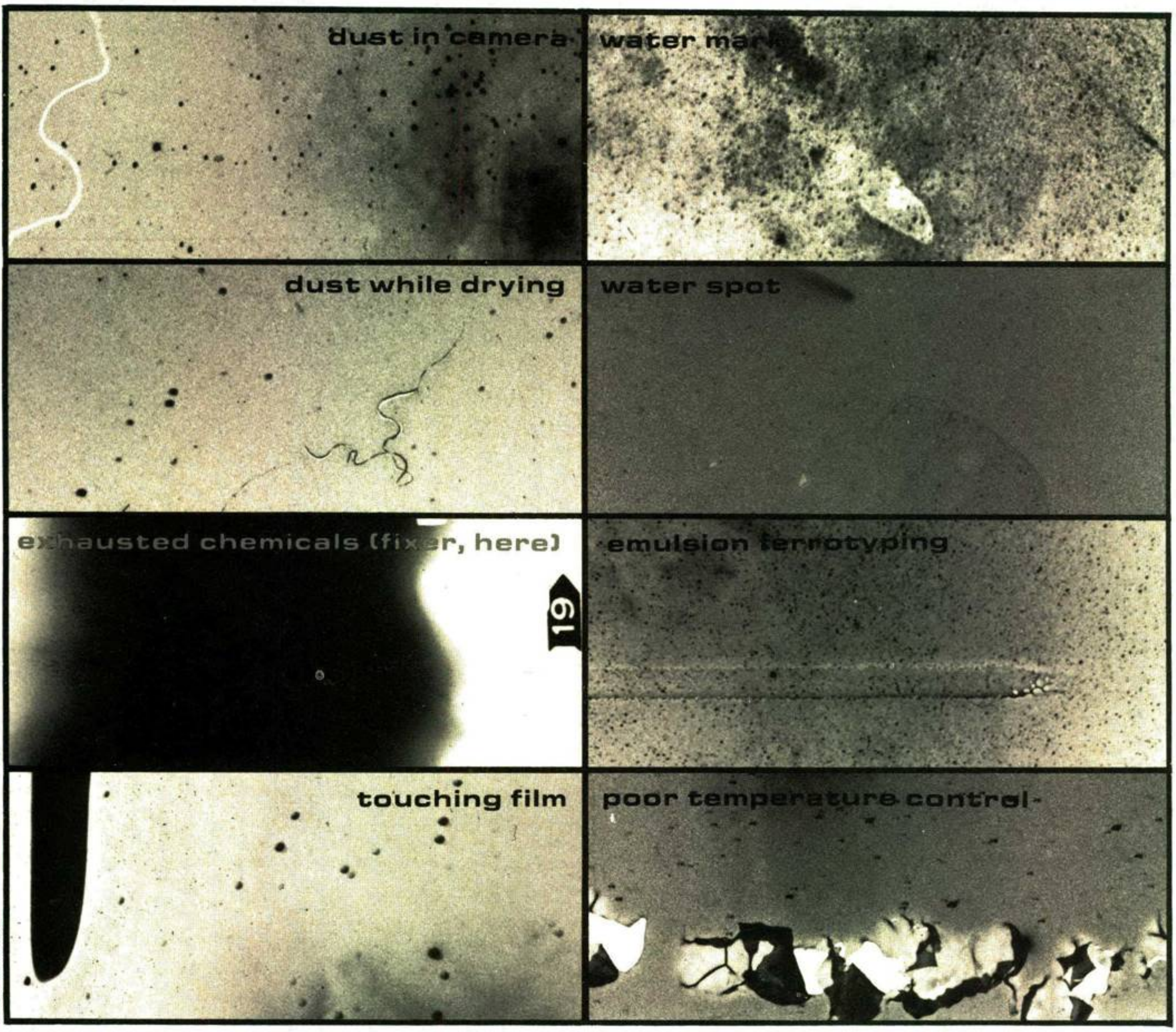
Then, holding the film by the edges, pick up the reel and insert the tape end of the film. Reels all work differently so whether yours is the "walk-in" kind or loads from a film gripper at the center, follow the manufacturer's directions. If the film sticks, binds, or winds crookedly, unreel it a bit and see what's caught. Avoid creasing the film since this will put little crescent-shaped glitches in the emulsion where they'll develop up and intrude visibly on your prints.

Repeat the above steps, first in full roomlight, then with your eyes closed, finally with the lights out (turning the light on again to see what happened costs you 10 points) until you can load that reel flawlessly. Pretend you're blind, and learn to "see" with your fingertips. When you feel comfortable in what you're doing, you're ready to try it for "keeps" on exposed film.

To start, mix up the chemicals in their storage bottles according to the instructions on their packages. Rinse the graduate and use it to measure out enough developer to cover the film in your tank. (How much is that? Read the instructions with the tank, but in most tanks eight ounces will cover one roll of 35 mm film; 15 ounces will do two.) Check to see if your developer needs dilution to working strength. If so, cut the stock solution you just mixed with tap water. Stick the thermometer into the developer and give it a few minutes to register while you prepare the rest.

On your darkroom counter, away from the chemicals, place the roll of film, bottle opener, developing tank,





David Hudgins

film reel, and scissors. Always lay them out the same way; habit is a mighty good friend when you work in the dark. From left to right, I place the tank (with cover in front), the reel, the film, the bottle opener, and the scissors — but I'm left-handed and you may prefer your own arrangement.

By now, the temperature of the developer should have stabilized — read the thermometer and check the film's data sheet to see how long you develop it. Standardizing your temperatures at 68° F (20° C) is a very good idea because many films were made for development at this temperature. When the temperature strays too far away from it, they suffer various defects. To adjust an erring temperature, place the graduate in a bath of hot or cold water to bring the solution to the right temperature.

Are You Ready?

Now for the moment of truth.

Take the real roll of exposed film, turn out the lights, and — with full confidence in your new-found skills — pry off the cassette bottom and load the reel. When it's loaded, plop it into the tank and put on the tank cover. Make sure the cover is closed properly, then turn on the lights.

For the sake of example, let's say you have a roll of Tri-X that you want to use D-19 developer on for extra-high contrast. At 68° F, Tri-X needs seven minutes' development time. Pour in the developer through the tank's light-tight trap. When all the developer is in, thump the tank gently on the counter to dislodge any air bubbles.

Proper and even developing and fixing requires you to agitate the solutions in the tank. The chemicals right next to the emulsion become exhausted and need to be replaced by fresh. Accordingly, tilt the tank back and forth, twirl its spindle, or whatever the manufacturer suggests for 10 seconds every minute. Be careful, though: too vigorous an agitation will cause air bubbles and streaks of uneven development, and too little agitation produces blotches of weak and uneven development — all irrevocable.

While the developer is working, rinse out the graduate and fill it with the correct amount of stop bath to cover the film. When the developer's time is up, either pour it back into a container (one of the wide-mouthed jars) or, if it's the "one-shot" kind, dump it down the drain. Pour in the stop bath and swish it around for one minute. While the stop bath is neutralizing the developer, rinse out the graduate again and fill it with the right amount of fixer.

Pour out the stop bath into a fresh holding jar, and then pour in the fixer — for five minutes if it's the ordinary kind, about two minutes if it's the "rapid-fix" variety. Agitate the fixer as you did the developer. When the time is up, pour it out into a holding jar. The tank can now be opened.

Place the tank and reel under the faucet in the sink and run water into it gently for 20 minutes to half an hour. Every few minutes, empty out all the water. Keep the wash temperature close to that of the chemicals — ideally 68° F.

As a last step before hanging the film up to dry, let the reel of film sit for a minute or two in a wetting agent like Kodak's Photo-Flo. This will allow your mineral-laden tap water to flow off the film evenly and eliminate its residue. Skipping this step means risking water spots that will mar your negatives. Hang the film up in a place where dust won't land on it, using a plastic clothespin on the bottom to help it hang straight.

While our negatives are drying, let's take a look at the question of reusing the chemicals. Developers, for example, fall into three types: one-shot, moderate-use, and long-lasting. Some, like D-76, are one-shot or moderate-use, depending on their dilution. Others, the long-lasting ones, need periodic replenishment. Fixers, ordinary or "rapid," have moderate lifetimes, as do stop baths.

Whatever the type, follow the manufacturer's suggestions to start with. They will provide information on each package about how many square inches of film a given amount of chemical will process — but these need some modification with astronegatives and emulsions.

The recommendations are based on ordinary negatives which have an average density; things change with astronomical subjects. Because sky photos usually make less demand on a developer (most shots have lots of dark sky, after all), it will last longer than Kodak says — but be careful how much you push them beyond the recommended limits. Developers oxidize quickly and often become useless before you deplete them.

Stop baths on the other hand store well and require no adjustment to the recommended lifetimes. If you're using the indicator kind, it will tell you (by changing color to purple) when it's worn out.

Fixers also keep but astronomical negatives overwork them, since they have to dissolve away all that unexposed emulsion. Check the recommended lifetime and divide by two.

What Went Wrong?

Two to six hours after you hang them up, your astronegatives will be thoroughly dry. Naturally, you're itchy to have a good look at them, so you hurry in, take them down from the line, and eagerly hold them up to the light. Suddenly, your stomach turns over — they're ghastly! You don't know what it is, but on nearly every frame there's this *stuff*, ruining the negative. Furtively, you scratch it lightly with your fingernail — AND PIECES OF EMULSION BEGIN TO COME OFF....

Donnerwetter!! What happened???

Well, lots of things maybe; it all depends on just what the stuff looks like. Take a hard look at our rogues' gallery of goofs and locate the one that most resembles what happened to you.

Let's go down the list and show how to avoid these miseries.

Dust. Maybe the commonest gremlin of all. Keep the inside of your camera clean. Dust it out with a soft camel's hair brush or a blast of compressed air. And when you've hung the negatives up to dry, resist the temptation to run in from time to time and moon over them. You'll only raise dust that will stick to the wet emulsion and not come off when dry.

Shot chemicals. Another common goof. You only have to wreck one roll to know that using solutions beyond their recommended working life is a very poor economy.

Film that touches. This usually comes from a clumsy job of loading the reel. Remedy: learn to do it carefully and correctly. Go back to the dummy roll and practice, practice, practice.

Water spots. Skipping the wetting agent may save a minute or two, but you have the results in your hands. Fortunately, careful rubbing may remove some of them.

Emulsion ferrotyping. When the film dries while it's in contact with something (like the roll hanging beside it), you'll get a ridge in the emulsion that's there for good.

Poor temperature control. Repeat after me: "emulsions are fragile, emulsions are fragile...." Keep all solutions and rinse water to within at least 5° F of each other or you risk the emulsion separating from the film stock.

On Beyond Tri-X

So much for basic or standard processing — what about push-processing or the spectroscopic emulsions and that weird brew you soup them in?

Push-processing, extended development, forced speed — whatever you call it, it usually means giving a negative more time in the developer. You do this to bring up faint details or to enhance contrast, though you pay a price: graininess always increases and sharpness decreases. Heavily exposed areas blacken up to such a density that you need extra care in printing to salvage details in them. And perhaps worst of all, the background density of the film + sky ("fog") will increase, placing a limit on how faint the objects are you can record.

But if you've never tried pushing a roll of film, you should, if only to see how it works. Experiment by giving one roll 25% extra development time, then try another roll 50% longer, and 100% on a third. Depending on how you like the results, increase to 200% or 300%. You'll soon see that for some objects (extended, low-surface brightness ones) it helps a lot; for others it's a disaster.

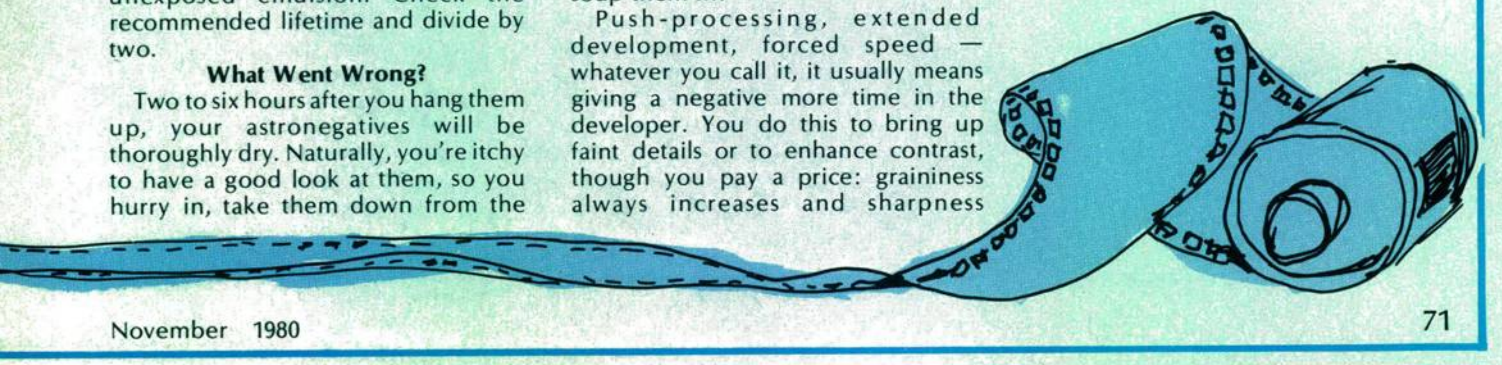
Spectroscopic films demand special handling and treatment. The 103a series are physically even more fragile than everyday films like Tri-X. You have to be careful. Terrible things happen to the emulsion — like curdling — if you take them out of a warmish developer, say, and plunk them into a coolish stop bath. Omit the ordinary acidic stop bath with 103a films, substituting a simple water rinse, because the acid bath will eat tiny pinholes in the emulsion.

The 103a films also have an anti-reflective backing to keep to a minimum the reflected and scattered light that surrounds a bright star image. Called rem-jet, it usually dissolves in the processing, but sometimes has to be carefully swabbed off with a cotton ball soaked in developer after the fixer has finished.

As with push-processing, try a specialty developer sometime. MWP-2 (which stands for "Mount Wilson/Palomar mix #2," from the observatory that created it) doubled the speed of the 103a series films. Order some from Clayton Chemical Co., 325 W. 132nd St., Los Angeles, CA 90061. Prices, not including shipping, are: $4 for a 1 gallon mix, $14 for 5 gallons. Although MWP-2 was specially formulated to get the most from the 103a films, it will also work on Tri-X and HP-4. Don't try it on the other emulsions.

Next installment, we'll take your negatives back into the darkroom and make some prints.

— *Robert Burnham*



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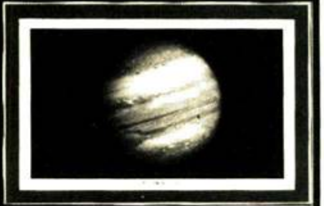

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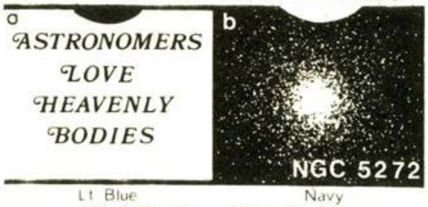

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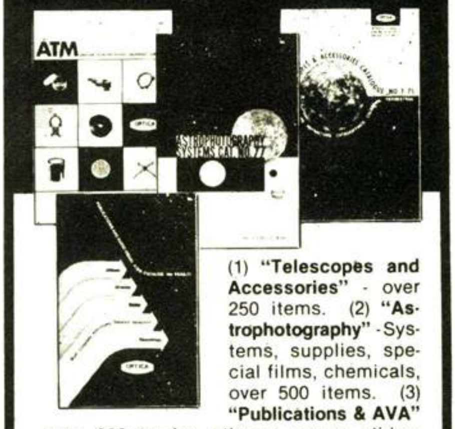
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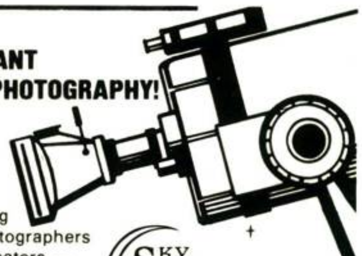

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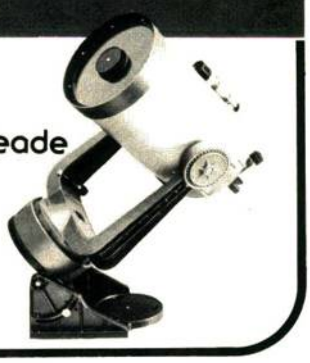

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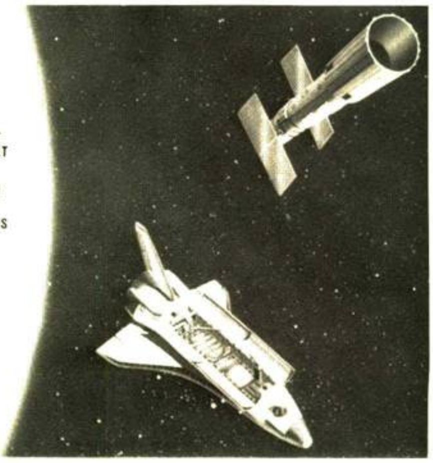

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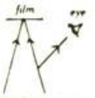

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ANNOUNCEMENT — The Center for Amateur Cluster Studies is a group of amateur astronomers who study, observe, and do specialized projects with both open and globular clusters. Contact C.A.C.S., National Coordinator, Route 2, Box 89, Anchorage, KY 40223.

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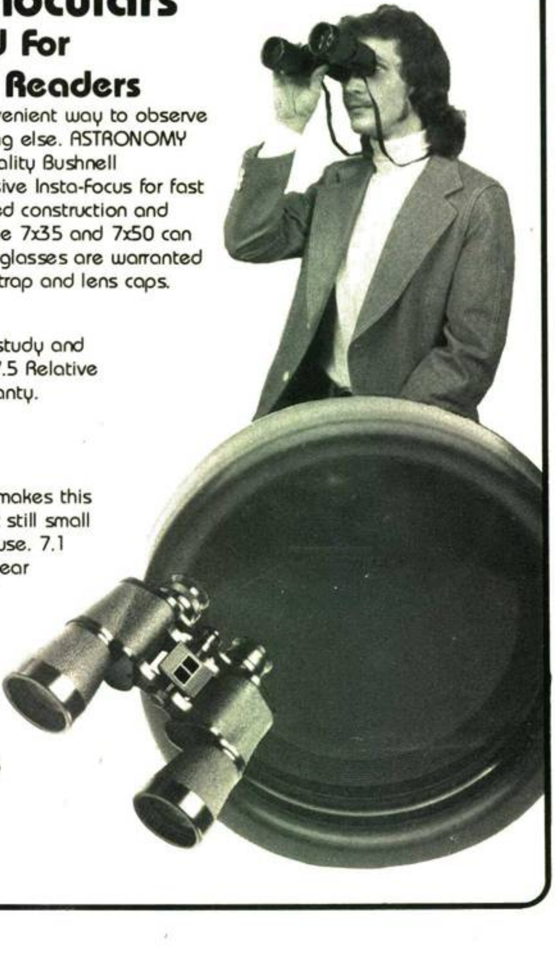

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Solar Pulsations Confirmed

Scientists working at the South Pole have confirmed a controversial observation made by the Stanford Solar Observatory that the Sun pulses every 2 hours 40 minutes, a finding that will force major revisions in scientists' models of the solar interior.

The confirmation comes from French scientists who were among the most vocal critics of the Stanford observation, and it caps a unique three-nation, four-continent investigation that has lasted for more than five years.

The pulsations are produced by a "pressure wave, something like a sound wave, coming from the interior region of the Sun to the surface where we can observe it," according to John M. Wilcox, adjunct professor of applied physics and director of the observatory. "It's very much involved with models of the solar interior, the density and composition of the interior."

The current models, or designs, of the interior of the Sun predict that there should be some slight pulsations every hour, Wilcox said. But the discovery that the pulsations occur more than twice that far apart probably means these models are wrong and "the theorists will have to go back to work."

The first observation of these pulsations was made in 1976 by three Soviet scientists, V.A. Kotov, A.B. Severny, and T.T. Tsap at the Crimean Astrophysical Observatory in Nauchny. They used a technique developed by Kotov that observes Doppler shifts on the surface of the Sun.

By measuring the shifts in green light (produced because of the presence of iron atoms in the solar atmosphere), they noted a slight bulge in the surface of the Sun every 160 minutes. This meant the whole Sun was expanding and contracting very slightly, said Dr. Philip H. Scherrer, a senior research associate at the Stanford Observatory who has worked with the Crimean scientists.

Because of the past close collaboration with the Crimean Observatory, Scherrer and Wilox decided to see if they could replicate the experiments. In science no discovery is considered solid until it is confirmed by other scientists working in another lab.

Last year, after more than 700 hours of observation at the Stanford facility, located in the foothills behind the campus, the Crimean observation was confirmed and a paper, written jointly by the two observatories, was published in the British scientific journal *Nature*.

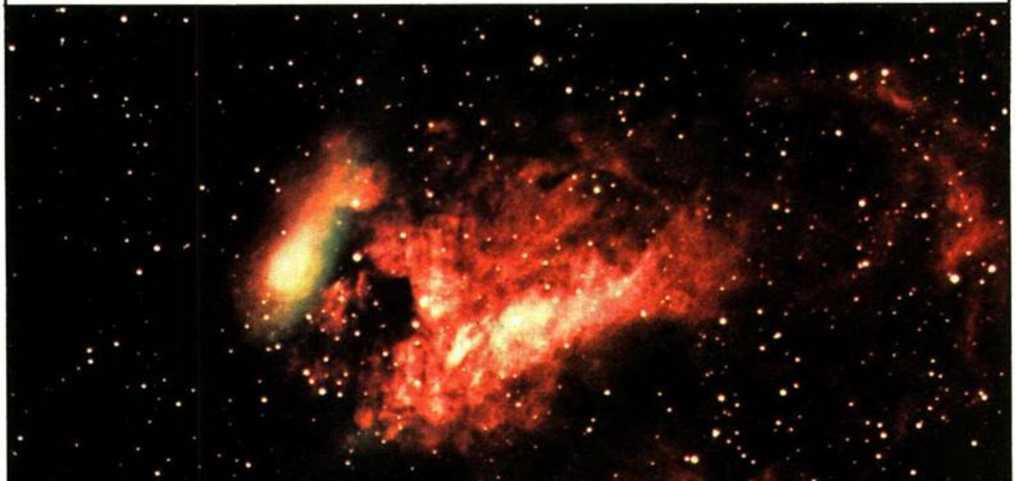
The Stanford confirmation did not settle the matter, however; a group of French scientists at the University of Nice entered the picture. Because the 160-minute pulsation contradicted the generally accepted model of what was happening on the Sun, the French scientists, headed by E. Fossat and G. Grec, looked for the pulsations and failed to find them.

This threw the issue into confusion, but because of the importance of the dispute the French, Soviet, and American scientists decided to collaborate. They joined forces with the Bartol Research Foundation of Philadelphia's Franklin Institute, which has two observatories in the Antarctic.

Working in the Antarctic has several advantages, Wilcox points out.

"There is no 24-hour fluctuation; they see the Sun for 24 hours," he said. "Furthermore, the Sun remains at essentially a constant angular attitude. Also, weather conditions

An Infrared Swan



Scientists at Caltech and NASA's Ames Research Center created this image of the Swan Nebula (M-17, also known as the Horseshoe or Omega Nebula) using data obtained from the Kuiper Airborne Observatory (see "KAO: Mission Incredible" in ASTRONOMY, June 1980). The picture shows how the nebula would appear if viewed through a large telescope sensitive to infrared light. Located in the constellation Sagittarius, this region contains a cloud of ionized interstellar gas excited by recently formed stars. Astronomers call this type of cloud an H-II region, which means it is composed of hydrogen (H) from which the electrons have been stripped. The M-17 H-II region is bounded on the southwest by a molecular cloud. The far-infrared radiation is brightest just adjacent to the H-II region, the result of thermal emission from dust grains, most of which are located outside the ionized hydrogen gas. The core of the molecular cloud is heated primarily by infrared radiation from dust within and next to the H-II region. The energy flow appears to be from the H-II region into the molecular cloud (shown schematically by color changes from green to red), illustrating the intimate association between an H-II region and the molecular cloud out of which it formed. NASA photo.

(during the austral summer) are such that they can have several days' uninterrupted run."

Working with Dr. Martin Pomerantz of Bartol, which is based at the University of Delaware, the French scientists made five days' continuous observations with an optical telescope located eight kilometers from the Amundsen-Scott Base, the permanent U.S. station at the geographic south pole.

The five days at the pole produced almost as much data as Stanford and the Soviets had been able to produce in an entire year.

The French scientists then took the data to the Crimea for analysis.

"A couple of weeks ago we got a telegram from them," Wilcox said. "It said: '160-minute oscillation is present in South Pole data. The amplitude is 33 centimeters per second and phase is in perfect agreement with yours.' "

The amplitude, or motion, is very small relative to the size of the Sun. Thirty-three centimeters per second is about a foot a second. Considering the Sun is 864,000 miles across, the whole bulge is too small to measure except by the most delicate of instruments.

The data produced over the years contain considerable circumstantial evidence to support the idea the scientists were really observing a solar phenomenon, and not being fooled by terrestrial interference.

If the pulsations were exactly 160 minutes, this would bother the scientists considerably because that is exactly one-ninth of a terrestrial day — an odd coincidence, since the rotation of the Earth and activity on the surface of the Sun have nothing to do with each other.

"A ninth of a day is 160.00 minutes," Scherrer said. "If the oscillations were exactly one-ninth of a day, I don't think we'd ever believe it was real...It makes you say this is probably not from the Sun, this is probably from the Earth's atmosphere. The Sun doesn't know how long a day is, and if your data say something about the length of a day, then you are probably not measuring the Sun."

But the data show a shift from year to year which would not happen if the origin of the readings was terrestrial, not solar. The shift measured from noon is 30 minutes per year, and the pulsations are clocked at 160.01 minutes.

"As far as anybody knows, that gets us off this problem of being one-ninth of a day," Wilcox said. "It's still awfully close," he added, "and we wonder, why is that?"

Another question is: Why did the French fail the first time they tried to replicate the experiment in Nice? The Stanford scientists think it was probably atmospheric interference over the Riviera. Even on clear days there is turbulence in the air there that could have easily masked the tiny shifts in the spectrum being measured.

The scientists are now convinced the observations of the pulsations are valid. "The theorists in the scientific community, including ourselves for that matter, will really have to take this seriously," Wilcox said.

Our turbulent Sun apparently pulsates about nine times each day. This H-alpha filtergram taken in July shows a solar prominence on the Sun's limb. Photo by Edwin Hirsch.

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Voyager 1 at Saturn

Here is a summary of the more important observations Voyager 1 will make of Saturn during its encounter this month (all times are PST received times):

- November 6: 140 photos.

Voyager 1 makes a variety of observations; range to Saturn runs from 9,300,000 kilometers (5,779,000 miles) to 7,900,000 kilometers (4,909,000 miles). Saturn, Titan, Rhea, Dione, Mimas, Iapetus, and the rings are subjects for Voyager's cameras.

Saturn's atmospheric features will be studied. Titan is the only satellite with an appreciable atmosphere — its surface (if visible) is a prime target.

The infrared radiometer performs calibrations as well as observations of the atmosphere of Saturn. All other instruments also make measurements.

- November 7: 201 photos.

First images of Saturn are from 7,877,000 kilometers (4,895,000 miles). Four photos near Saturn will be used to search for new satellites. Titan is a prime imaging subject. Rhea and Iapetus will also be photographed. Iapetus is of interest because one side is bright, while the other is dark — the difference in brightness is a factor of six. Ultraviolet and other instruments measure Saturn, its rings, and the satellites.

- November 8: 173 photos.

The opening range to Saturn is 6,514,000 kilometers (4,048,000 miles). Satellites are prime imaging targets: Tethys, Titan, Enceladus, Rhea, and Dione. Saturn pictures and photographic searches for

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new satellites continue.

- November 9: 299 photos.

Voyager is 5,215,000 kilometers (3,240,000 miles) from Saturn as the day begins. An east-to-west infrared map is started. Photographic searches for new satellites continue.

- November 10: 427 photos.

Photos of Saturn begin when the spacecraft is 3,879,000 kilometers (2,410,000 miles) from Saturn.

The infrared east-west map of Saturn is complete early in the morning and the day ends as work on an infrared north-south map begins. The north-south IR map measures latitude and longitude variations in temperature and composition.

Satellite photos are made (one every 22½° for surface mapping) of Rhea, Tethys, and Dione. Titan photos are for atmospheric studies and mapping (only if the surface is visible). The imaging scientists believe that Titan's atmosphere is so opaque that even the extremely close-up pictures may not reveal the satellite's surface. The best opportunity appears to be a slim chance that a few holes in the clouds may provide occasional glimpses of the surface.

- November 11: 257 photos.

Saturn photos start when Voyager 1 is more than 2.5 million kilometers (12,553,000 miles) distant (part of the continuing infrared north-south map carried over from Nov. 10).

The optimistic among fields and particles experimenters are looking for signs of Saturn's magnetic field — the bow shock.

In mid-morning the spacecraft performs a fields-and-particles maneuver: 384° roll to lock on the star Beta Carinae to sample the region around Saturn. It may be out of communication with Earth from 9:52 a.m. to 10:37 a.m.

The first event after this maneuver is a 16-photo sequence of Titan, to study atmospheric dynamics and map the surface, if visible.

A plasma-wave observation in the evening (6 to 6:05 p.m.) is one of a long series of measurements inside Saturn's magnetosphere. Plasma-wave structure affects interpretation of other fields and particles experiments.

Closest approach to Titan (followed by Titan-Earth and Titan-Sun occultations) occurs at 11:06 p.m. A number of important Titan photo sequences are made.

A large share of the Titan data around closest approach will be recorded for playback to Earth later. Titan-Earth occultation runs from 11:12 p.m. to 11:25 p.m.

Voyager 1 crosses Saturn's ring plane inbound at 11:23 p.m.

- November 12: 315 photos.

This is closest-approach-to-Saturn day. First photos of Saturn are taken from a range of 955,900 kilometers (593,900 miles); final pictures are from a range — beyond the planet — of 330,000 kilometers (205,000 miles).

Closest approach to Tethys (415,320 kilometers or 258,067 miles) occurs at 3:41 p.m. and closest approach to Saturn (124,200 kilometers or 77,174 miles) occurs at 5:11 p.m.

Closest approach to Mimas (108,400 kilometers or 67,356 miles) takes place at 6:02 p.m. This is closest approach when satellite is lighted; the actual closest approach doesn't occur until 7:07 p.m. — when Mimas is in the shadow of Saturn.

Earth occultation begins at 7:07 p.m. and Sun occultation begins a few minutes later at 7:20 p.m.

Closest approach to Enceladus occurs at 7:15 p.m. at a distance of 202,521 kilometers (125,840 miles).

No telemetry will be received from Voyager 1 for five hours, begining at 6:34 p.m.

Sun occultation ends at 8:03 p.m. and Earth occultation ends at 8:36 p.m. Ring occultation begins soon afterward.

Closest approach to Dione (while it is lighted) occurs at 8:53 p.m., and closest approach to Rhea takes place at 11:46 p.m. at a range of 72,100 kilometers (44,800 miles).

- November 13: 201 photos.

A primary target for the instruments is the rings of Saturn: mostly infrared measurements and photos. There are some special observations of Saturn: the ring shadow, north and south poles for composition differences there, searches for auroras and lightning in the atmosphere, and opacity measurements to find compositional differences between belts and zones.

Satellites to be photographed include Iapetus, Titan, Dione, and Rhea.

The day ends with another north-south infrared map to determine temperature, composition and heat balance on the dark side of Saturn.

- November 14: 176 photos.

IR north-south map continues. From 9:48 a.m. to 5:59 p.m. the spacecraft takes 154 photos of the rings.

Closest approach to Iapetus (more than 2 million kilometers or 1,243,000 miles) occurs at 12:50 p.m.

- November 15: 157 photos.

Between 3:58 a.m. and 4:43 a.m., Voyager 1 takes a series of long-exposure (15 seconds each) pictures of Saturn to search for auroras and lightning in the atmosphere on the dark side. The range is 3,570,000 kilometers (2,218,000 miles). An east-west infrared map, with supporting photos, begins at 5:23 a.m.

Photos of Saturn, Titan, Rhea, and Iapetus are taken throughout the day.

- November 16: 424 photos.

A search for new satellites outside the Roche Limit opens the day.

A series of photos for the post-encounter motion picture begins at 2:53 a.m. Then, beginning at 8:41 p.m., and continuing until 6:46 p.m., Nov. 17, Voyager 1 will take a series of 276 photos of Saturn for the post-encounter rotation movie sequence. The series, with simultaneous infrared observations, will be most of the science received for the next 22 hours.

- November 17 & 18: 276 photos each day.

Most of these days are taken up with photographing the planet for post-encounter rotation films. A second such exercise begins at 8:38 p.m., Nov. 17, and runs until 6:44 p.m., Nov. 18.

Virginia Law on Light

On July 1, 1980, the following new law took effect in the state of Virginia:

"Code of Virginia, section 15.1-29.8:

Regulations of outdoor lighting near certain facilities. — In addition to any other authority granted to local governments by law, the governing body of every county, city, and town may regulate by ordinance outdoor lighting within an area one-half mile around planetariums, astronomical observatories, and meteorological laboratories. This statute shall be construed to affect any ordinance

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heretofore adopted by a local government."

Virginia's new local option legislation is more conservative than the 1975 Arizona state law on light pollution but there are some similarities. Some, though not all, states won't permit local governments to initiate legislation in new areas like light pollution. The state legislature must first give counties, cities, and towns the right to pass such ordinances or the state attorney general can throw out the local ordinance. The Virginia law is only the third statewide bill on light pollution.

Will the bill encourage astronomers to check with their local political representatives? In the opinion of June LoGuirato, chief lobbyist for the new Virginia statute, astronomers have very little impact on politicians because scientific people expect to get something for nothing.

"The Virginia politicians I've seen in seven local political campaigns aren't too impressed by high sounding degrees or an appeal for conservation of resources," said Ms. LoGuirato. "They want to know if you will donate $30 and 30 hours work to their political campaign. No donation during the campaign, little assistance on light pollution legislation during the legislative session." That's the first "law" of astropolitics. "Astronomers also don't realize that the 'laws' of astropolitics sometimes call for illogical actions," she added.

When the Virginia General Assembly held two public committee hearings on a light pollution bill, there were no opposition speakers. Nonetheless, the original Virginia Senate Bill #16 was amended five times by the legislators.

Virginia Governor John Dalton (seated) signs into law Virginia's new light pollution legislation, on April 1, 1980. Present at the ceremony in Richmond are (left to right): Astronomical League member June LoGuirato, Delegate John Rust, Jr., and Senator Charles Waddell, all of whom worked to pass this local option conservation legislation. Photo courtesy of Virginia Dept. of Highways & Transportation.

Robots in Space

An orbiting space factory, a self-directed deep-space exploration robot, a fully-automated Earth resources and environment monitor — even a lunar base that could grow through self-replication of many of its elements — have been examined in a space technology assessment workshop, looking at the next 25 years.

Robotics, artificial intelligence, automation, and remotely operated systems are vital to the future of these missions. The enormous benefits of such capabilities at relatively low cost have prompted a joint NASA/American Society of Engineering Education summer study at the University of Santa Clara in California.

The workshop was structured to select and define a set of exciting and challenging space missions that would identify critical technology needs for future research and development. As such, they are representative of possible future missions rather than specific proposals.

Feasibility analysis has concentrated primarily on four areas:

1) A highly versatile "intelligent" satellite information system for most types of Earth survey. Previous systems have suffered from the fact that they record everything they "see," producing huge masses of data.

The proposed information system would do substantial amounts of selection and interpretation of the data incoming from its sensors to provide results tailored to the specific needs of the requester.

In one approach, the system would possess its own "world model," stored in a ten trillion bit data memory. This would provide reference knowledge of the region of the requested observation.

The satellite would report exceptions to this reference model, such as changes in crop conditions, discarding such well-known phenomena as icebergs, lakes, and other landmarks. This would result in a major reduction in the amount of data that must be transmitted and analyzed. The world model would be updated to reflect latest dynamic conditions.

2) A second concept is a Deep Space Exploration system to provide reconnaissance, exploration, and intensive surface study of planetary bodies.

Specifically, the group is looking at a mission to Saturn's planet-sized satellite, Titan. (Titan has an atmosphere and is bigger than the planet Mercury.) The proposed, self-directed system would combine the functions of several previously separate missions: orbiter, atmospheric probe, and mobile surface exploration vehicle.

The vehicle would observe such a relatively unknown environment, and modify its "knowledge model" and exploration techniques, based on what it had observed. Major improvements in remote sensors, as well as advanced computer "intelligence," are required to select surface regions for more intensive investigations.

Such self-directed systems could be used to explore distant bodies within the solar system, the outer planets and their satellites, comets, and asteroids. It is also the type of system required for the eventual exploration of planetary systems of other stars, where flight and communication times of many years preclude manned involvement and interaction.

3) A third area is a facility for use of nonterrestrial materials (from asteroids and moons of Earth and other planets). This would be a permanent, automated Earth-orbiting facility initially using the space environment for unique processing of Earth-supplied raw materials. It would progressively make greater use of nonterrestrial materials. The group is identifying processing and manufacturing techniques well adapted to the space environment. Basic "starter facilities" are being identified, to be capable of producing a wide range of products and other tools to expand the facility capability.

4) Finally, the workshop defined, as an ultimate challenge for advanced automation, a factory on the Moon which would use lunar materials and could replicate itself. One of its first products would be another lunar factory, or factory segment. Such an automated, reprogrammable, self-replicating factory has been of theoretical interest for a number of years as a way of rapidly expanding utilization of space resources. The workshop has developed "proof-of-concept" designs and surveyed the types of logical organization for such a factory, as well as the requirements for an Earth-based demonstration of the concept.

Silencing Mars

Engineers at the Jet Propulsion Laboratory, Pasadena, California, sent a radio command to NASA's Viking Orbiter 1, switching off its transmitter and ending the spacecraft's four-year mission in orbit around Mars on Thursday, August 7.

Kermit Watkins, Viking project manager, said the orbiter was shut down because its attitude control gas was expected to be depleted before it completed its next orbit of Mars.

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"By sending the turn-off command," Watkins said, "instead of allowing it to occur automatically on the spacecraft, we will be sure that the radio transmitter has been shut off."

Although silent, the spacecraft will continue to orbit Mars well beyond the turn of the century to prevent contamination of the planet's surface for future missions.

Viking engineers have been carefully monitoring the spacecraft since late July in the expectation that it would soon use the last of its attitude control gas and therefore be unable to maintain the correct orientation. Attitude control gas keeps the spacecraft's radio antenna pointed to Earth and the power-producing solar panels aimed at the Sun.

Viking 1 was launched on August 20, 1975, from Cape Canaveral, Florida, and achieved Mars orbit on June 19, 1976. It has been operating continuously since then.

Viking Lander 1 continues to collect scientific information on the surface of Mars. It is programmed to transmit to Earth, weekly when interrogated, until December 1994.

Still Hope for Space

Space scientists, feeling the cold hand of accountants tightening the purse strings, might take some encouragement from the successful High Energy Astronomy Observatory program.

"I believe there is an object lesson here," said Dr. Thomas Mutch, NASA associate administrator for space science. "HEAO fell victim to that kind of budget crisis we are now experiencing."

When it was started a decade ago, Marshall Space Flight Center and TRW, the contractor, saw it as a pair of 10-ton, 40-foot-tall satellites, but restrictions on the NASA budget in 1973 nearly killed the project. But Marshall and TRW rapidly redesigned HEAO into a trio of 3½-ton, 20-foot-tall satellites launched on Atlas-Centaur rockets instead of more costly Titan 3Cs. Although the project was smaller than it started out to be, it has revolutionized X-ray astronomy and astrophysics as a whole.

Mutch commented at the second of two special NASA awards ceremonies for HEAO team members:

"HEAO is not just good science, but an example of what enthusiasm, tenacity, innovation, persistence, and teamwork can accomplish."

Another Jovian Moon?

Dr. Stephen P. Synnott, a Voyager Project navigator at the Jet Propulsion Laboratory in Pasadena, CA, who discovered a 15th moon of Jupiter last spring, has done it again. He has discovered a 16th jovian satellite while searching through photos taken last year by NASA's Voyager spacecraft to confirm the discovery of a 14th satellite.

Synnott's newest discovery, tentatively numbered 1979 J3, is about 40 kilometers (25 miles) in diameter. It circles the planet once in 7 hours 4 minutes 30 seconds, with an uncertainty of three to five seconds.

This latest discovery came from the same process by which he found the 15th satellite in March 1980. Synnott believed at that time that he had confirmed the earlier sighting of the 14th satellite because they had similar orbits and sizes. "But when I coupled data from Voyager 1 and Voyager 2," he said, "I found that the object I was looking at was on the opposite side of the planet — it couldn't be J14, so it had to be a new one."

The new 16th satellite appears to orbit near the outer edge of Jupiter's ring — also discovered in Voyager photos. The orbit is about 56,200 km (35,000 mi.) above the cloud tops.

Synnott still has not confirmed the existence and the orbit of the satellite 1979 J1, discovered in October 1979 from Voyager 1 data. "I've looked at hundreds of frames," he said, "but it's either too small to see in the pictures or the pictures didn't happen to be taken at the right instant." Synnott's search for confirming evidence of the 14th satellite (1979 J1) continues.

Before Voyager 1 reached Jupiter, the planet was believed to have 13 satellites. But in October 1979 a 14th was found — the one Synnott has not been able to confirm. Synnott discovered the 15th jovian satellite last spring. His latest discovery, number 16, was made in July.

Joseph Ashbrook

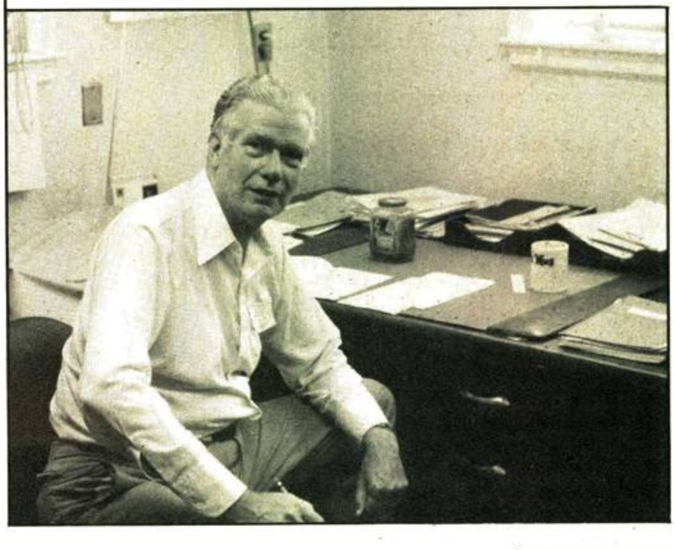
Joseph Ashbrook, the editor of *Sky and Telescope* since 1964, died on August 4. He was 62 years old.

A graduate of Johns Hopkins University, Ashbrook received his Ph.D. in astronomy from Harvard University. To his particular interest in the study of variable stars he very early added a life-long fascination with the history of astronomy. In 1953 he left Yale University, where he had been teaching astronomy, and returned to Cambridge as a research associate at the Harvard Observatory and assistant editor at *Sky and Telescope*.

Ashbrook was the first professional astronomer to join the staff of the magazine, and his editing and writing skills soon became apparent. In 1956 he became technical editor, and in 1964 he was made editor of *Sky and Telescope*, the position he held until his death. His interest and expertise in the history of astronomy were evident in the bi-monthly column "Astronomical Scrapbook," which he had authored since 1954.

Ashbrook was a member of both the American Astronomical Society and the International Astronomical Union. A member of the American Association of Variable Star Observers since 1936, and often a member of its council, his contributions to the field of variable star observing, both personally and organizationally, were immense. Also an active member of the Association of Lunar and Planetary Observers, Ashbrook served as a jovian satellite eclipse recorder for that organization during the last several years. His careful and meticulous study of the history of astronomy, particularly with regard to old observations of comets and asteroids, was often of great value to the science in the present.

But undoubtedly his greatest contribution to the field of astronomy was as editor of *Sky and Telescope*, for during his tenure the magazine served both professional astronomers and dedicated amateurs everywhere with articles and information of consistently high quality and value. His untimely passing is a loss felt throughout the astronomical community and beyond.



Joseph Ashbrook, 1918-1980.
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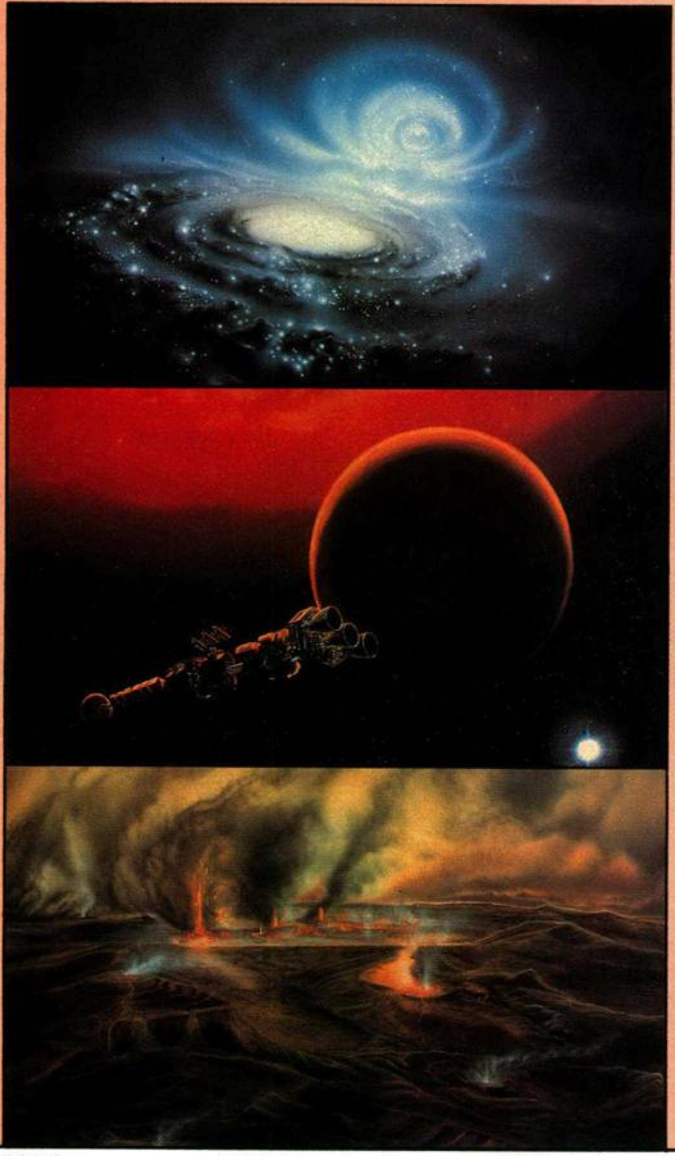

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REVIEWS

Open and Globular Clusters
Vol. III, Webb Society Deep-Sky Observer's Handbook
Kenneth Glyn Jones, ed.
206 pages, softbound, no price given
Enslow Publishers, Hillside, New Jersey 07205 (1980)

In 1967 a group of British amateur and professional astronomers banded together to create the Webb Society, named for the Reverend Thomas William Webb, eminent British amateur observer and author of the classic *Celestial Objects for Common Telescopes.* The stated aim of the Society is "to encourage the study of double stars and deep-sky objects." Partially in order to fulfill this self-imposed charge, the group planned a series of observer's manuals to be edited by Kenneth Glyn Jones, author of the unfortunately out-of-print *Messier's Nebulae and Star Clusters.*

Open and Globular Clusters is the third and most recent volume of the *Webb Society Handbook.* Readers familiar with the two preceding volumes will be pleased to find Vol. III equivalent in scope and authority. Like its forerunners, Vol. III is complete in itself with respect to its subject. The book is crammed with practical observing data, drawings, and a remarkable amount of specific and illuminating information pertinent to stellar clusters.

Although the *Handbook* is designed primarily for "the more experienced amateur who seeks greater scope for the exercise of his skills, a beginner will certainly find the volume functional now and even more so as personal interest and knowledge grow.

Vol. III contains a commanding number of clusters for the eager observer. Indeed, popular cataloger Charles Messier observed and cataloged only 28 globular and 27 open clusters. Impressively, Vol. III offers 205 open and 63 globular clusters, making the book a veritable treasure-house of clusters within reach of most common telescopes of modest aperture — nearly all Webb Society-cataloged clusters are brighter than tenth magnitude.

While written in somewhat technical language, Vol. III is of significant value just for the field drawings and accompanying commentary, particularly since this enormous selection of clusters cannot be found in total in any other single non-professional source.

The first forty pages of the book treat historical aspects of the two types of stellar associations, their general relationship to the Galaxy, structure of the clusters, in addition to offering a concise survey of many hard-to-find professional catalogs.

Summarizing the excellent opening material in just one paragraph is not meant to imply shallow treatment of the topics; rather, the few pages contain a wealth of information that is current, specific, and accurate. There is no question that a great deal of exacting and demanding research went into these pages.

However, the majority of readers may well find the portion of the book following the introductory material to be of greatest value and use, for the book is essentially a catalog.

Each cluster, in addition to being labeled by its original catalog number, has been given a WS (Webb Society) number. Each object is numbered sequentially from the preceding volume, thus Vol. III contains objects WS 162 through WS 429. Data given for each cluster include epoch 1975 coordinates, visual magnitudes, sizes, types and concentrations, and the home constellation for easier location.

The visual descriptions are all strictly eyeball measurements so magnitude, color, shape, and such criteria may not agree with every observer's eyepiece judgement. The descriptions are terse and to the point, apparently objective, but in many instances lack the charm and color that annotations in Rev. T. W. Webb's little volumes have. Nonetheless, coupled with the field drawings, the descriptions are thoughtful and give much to the observer, casual or otherwise.

All observations were made by Society members who used instruments ranging from 7 x 50 binoculars to telescopes having sixty to three-inch apertures, mostly in the eight to ten-inch category.

An example of the visual description of the popular summertime favorite M-11, NGC-6705, or as the Society numbers it, WS 283, follows:

"(12-inch) A beautiful sight, one of the most impressive with this aperture; almost a globular.

"(8-inch) An impressive, compact cluster; the densest part in the shape of an arrowhead with an 8 magnitude star just inside the apex; the densest part is about 10′ or 12′ diameter.

"(6-inch) Shows a starless vacuity and much nebulosity of unresolved stars."

A field drawing located opposite the description portrays what you might realistically expect to see in the eyepiece. The drawings are about two inches in diameter, sufficiently large to have the stellar images in them drawn to scale and readily seen. Below each rendering is the catalog number, aperture and magnification used for the drawing, the size of the field, and the name of the Society observer.

The Society's statement that the *Handbook* "is intended to be a replacement for the Rev. T. W. Webb's *Celestial Objects for Common Telescopes* which is more of historical than practical interest to the amateur of today" might be true, but many owners of Webb's useful classic would quite possibly be in disagreement with the Society's intent.

Nevertheless, Vol. III will find extensive use at the eyepiece. The book is practical, comprehensive, and is an excellent guide to the observation of open and globular clusters. It should do much to popularize these stellar wonders and if this is the intent of the Webb Society, it should be a resounding success. *Gail O. Clark.*

Cosmic Landscape: voyages back along the photon's track
Michael Rowan-Robinson
149 pages, hardcover, $12.95
Oxford University Press

We see everything about us through an exceedingly narrow portion of the electromagnetic spectrum labeled the visible band. To either side of this small range lies a tremendous, unseen continuum of frequencies whose perimeters have yet to be accurately determined.

If by some alchemy we might extend our limited visual sense to include frequencies below the violet end and above the red end of the spectrum, we would presumably perceive strange and wonderful sights. In astronomy particularly, new and startling visions would loom before us and phenomenal scenery would become a part of our visual experience.

Just such a scenario is the dominant theme behind Michael Rowan-Robinson's *Cosmic Landscape: voyages back along the photon's track.* Preceded by a skeletal explanation of light, color, and elementary wave theory, Rowan-Robinson charts the course for his imaginative, but factual, book with these words: "...we have a receiver that can be tuned to all possible wavebands — the all-frequency light machine. Each band is connected to a suitable telescope which can instantaneously scan the whole sky. The results are fed to a special pair of spectacles so that you can see the sky as it appears to the telescope working in any particular band. What do you see as you tune across the wavebands?"

The engrossing answer unfolds as the author transports the reader through space and time on six remarkable voyages. Acompanying six photons of different wavelengths back to their individual sources, the armchair traveler is expertly guided on the exotic journeys, or as Rowan-Robinson refers to them, "landscapes."

The six nearly identical landscapes are seen through the visible band, radio band, ultraviolet band, the X-ray and gamma ray bands, the infrared band, and the microwave band. Each description unveils visual secrets unknown to our limited human vision.

This book, unlike many popular level astronomy books, is totally devoid of photographs, drawings, or other graphics. Other than one desirable exception, they simply are not needed to enhance the quality of the book. The exception: a diagram depicting the electromagnetic spectrum would be useful and should have been included. Hopefully, any future revision would take care of this omission.

While not at all technically demanding, metric description is used exclusively. And it will be noticed that Englishman Rowan-Robinson refers to the Big Dipper as the Plough. Similarly, the constellation Scorpius becomes Scorpio.

The author differentiates between visible and nonvisible astronomy as the old and the new astronomies. His adeptness at providing cogent explanations of many of the basic tenets of modern astronomy while at the same time regaling the reader with superb and colorful description, blends the old and the new into a complementary whole. Moreover, his knack of inserting brief summary statements here and there supplements the book's overall intelligibility.

Rowan-Robinson has the uncommon ability of portraying clearly and impressively his personal assumptions, in addition to accepted scientifically accurate theories of just what might be visible in the universe when examined at various wavelengths. Indeed, his engaging style, wit, and lucid writing are favorably comparable to that of popular astronomy writer William J. Kaufmann, III.

The initial third of the book is devoted to the visible astronomical landscape: the solar system, various stellar types and formations, galaxies, and the expanding universe. A searching look reaching to the limits of the known visible universe creates a solid foundation for the balance of the book.

According to Rowan-Robinson, "the rivers of light flow to our eyes, and we shall trace them back to their source." So, following the visible band tour, it's back to Earth to commence another imaginary circuit which encompasses a different segment of the unseen spectrum.

For instance, we learn that the microwave landscape seen from Earth appears to emit a faint background glow in all directions. A strange universe is revealed while following the microwave photon back through space and time to its origin. Density of the universe increases as you draw nearer its creation. The universe becomes perceptibly smaller. The journey continues until arrival at the state of near-ignition of the cosmic fireball. Temperature and density continue to increase at an incredible rate until Einsteinian physics manifest themselves in the pre-Big Bang condition. Hadrons, antiparticles, various colors and flavors of quarks are all-pervasive while just a tiny fraction of a nanosecond farther down the track of the photon lurks the ultimate beginning of the universe.

Cosmic Landscape is a thoughtful, provocative, and accurate attempt to explain the invisible universe in a fascinating, you-are-there manner. Nearly everyone will benefit by joining Rowan-Robinson on his voyages through a universe that unfortunately we will never be able to view firsthand. *Gail O. Clark.*

The State of the Universe
Geoffrey T. Bath, ed.
199 pages, hardcover, $24.95
Clarendon Press (Oxford University Press) 1980

The ambitious-sounding title isn't too far off the mark when you consider that most of the "hot" topics of modern astronomy are dealt with in this compilation of eight articles by leading British astronomers.

Dictionary of Astronomy, Space, and Atmospheric Phenomena
David F. Tver
281 pages, hardback, $17.50
Van Nostrand Reinhold (1979)

Intended for the general reader, this dictionary has simple, straightforward definitions and explanations of many celestial phenomena. After the main body of entries, there are several tables of data (moons, planets, small solar system objects, stars, etc.) in an appendix.

General Relativity and Gravitation
A. Held, ed.
1,137 pages, 2 vols., hardcover,
$115/set
Plenum (1980)

Subtitled "100 years after the birth of Albert Einstein," these two fat volumes provide 31 review articles devoted to a technical exposition of what relativity research has done, and offers some prospects of where it is going.

Elementary General Relativity
C. Clarke
131 pages, paperback, $18.95
John Wiley & Sons (1980)

If you find "...a little basic calculus (simple differential equations, partial derivitives, and the wave equation)" along with "some linear algebra (vectors, matrices, and the idea of a vector space)" elementary, then this is just the book for you. Others may want an even more elementary approach.

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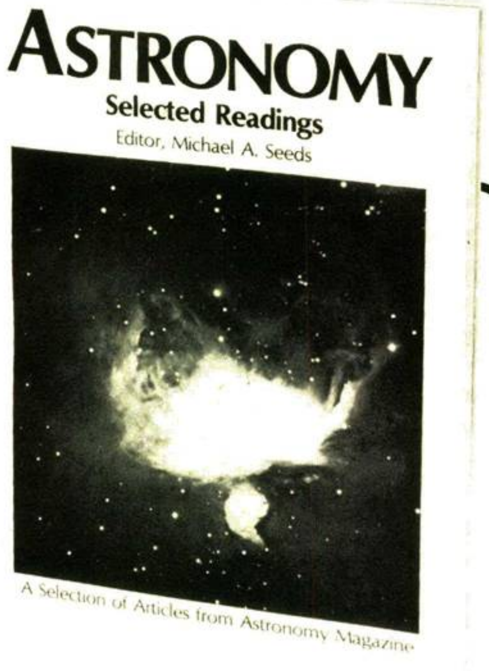

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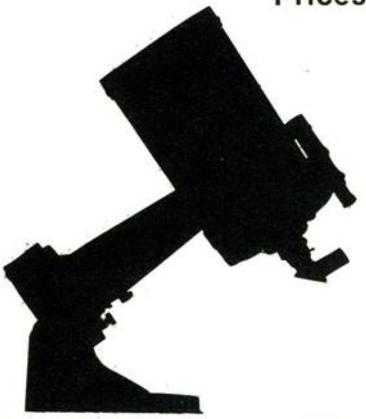

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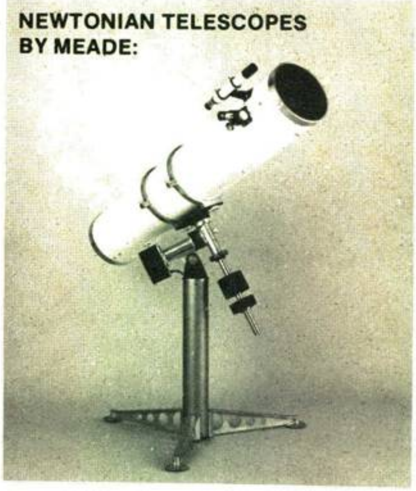

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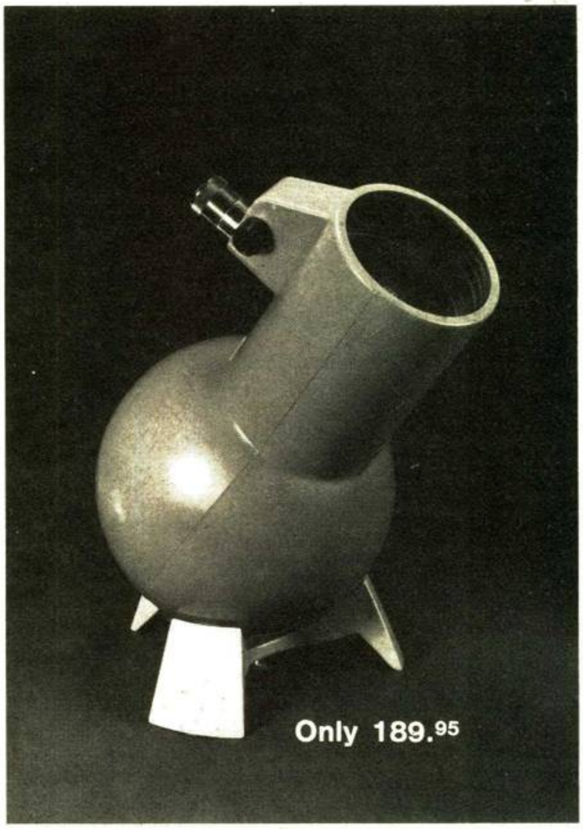

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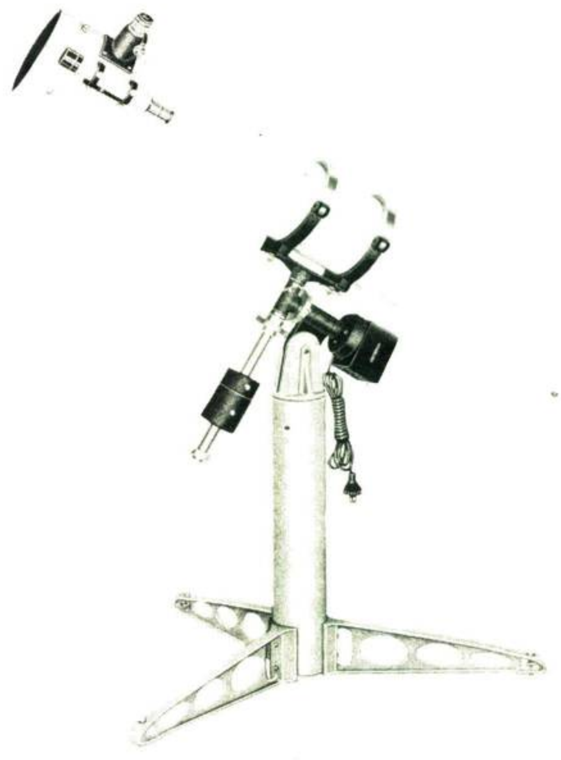

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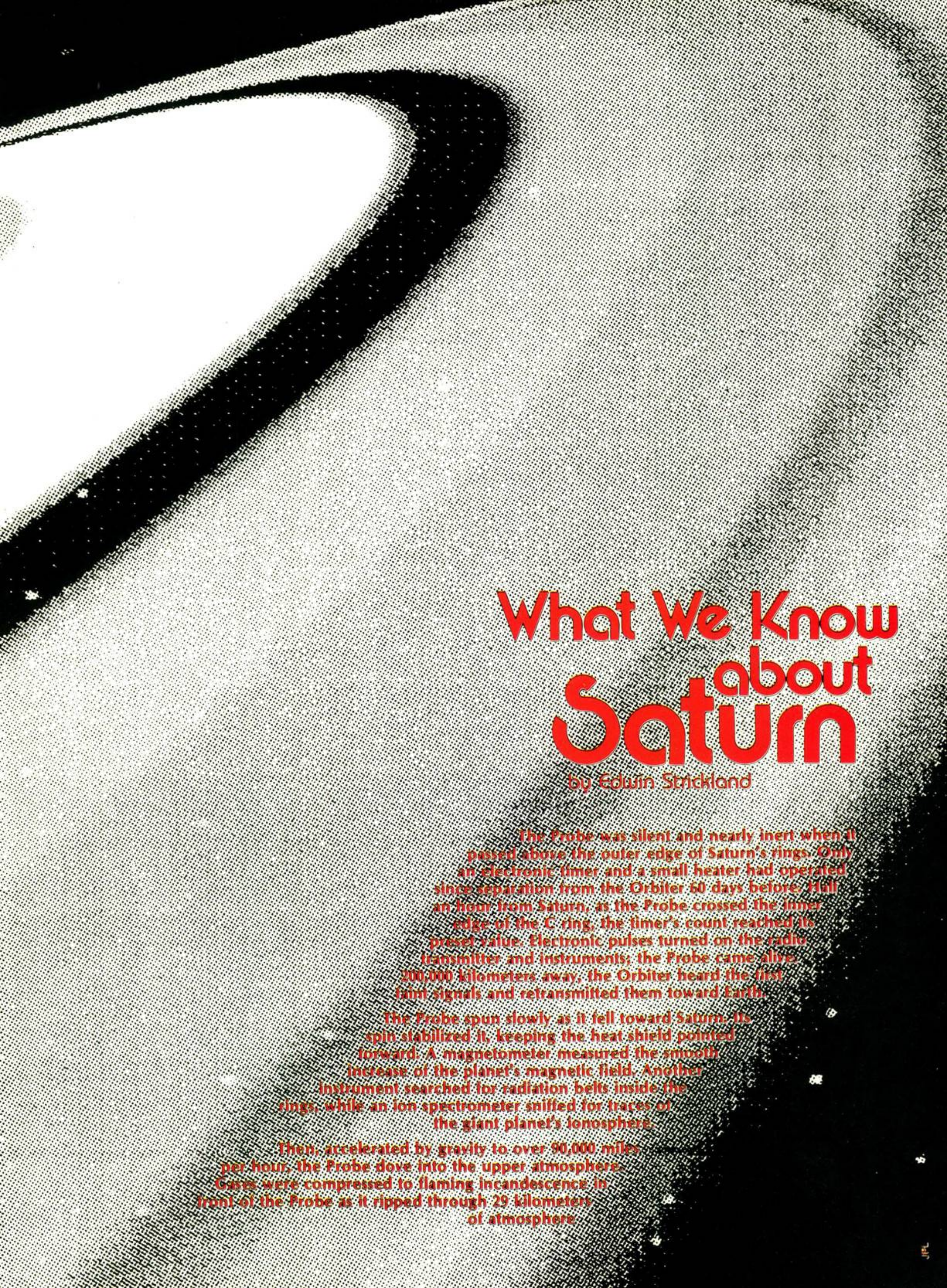


JPL

What We Know about Saturn

by Edwin Strickland

The Probe was silent and nearly inert when it passed above the outer edge of Saturn's rings. Only an electronic timer and a small heater had operated since separation from the Orbiter 60 days before. Half an hour from Saturn, as the Probe crossed the inner edge of the C ring, the timer's count reached its preset value. Electronic pulses turned on the radio transmitter and instruments; the Probe came alive. 200,000 kilometers away, the Orbiter heard the first faint signals and retransmitted them toward Earth.

The Probe spun slowly as it fell toward Saturn. Its spin stabilized it, keeping the heat shield pointed forward. A magnetometer measured the smooth increase of the planet's magnetic field. Another instrument searched for radiation belts inside the rings, while an ion spectrometer sniffed for traces of the giant planet's ionosphere.

Then, accelerated by gravity to over 90,000 miles per hour, the Probe dove into the upper atmosphere. Gases were compressed to flaming incandescence in front of the Probe as it ripped through 29 kilometers of atmosphere every second. The Probe raced through the upper stratosphere, slowing rapidly; deceleration hit 350 Earth gravities. No instrument could survive and take measurements during that flaming entry. Instead, the Probe itself became the instrument: an accelerometer measured its slowing plunge through the atmosphere. Super blowtorch heat of 5000 watts on every square centimeter boiled away the surface of the heat shield. A fireball streaked across the afternoon sky above Saturn's hazy clouds.

The meteoric plunge finally ceased in the planet's lower stratosphere. When the accelerometer sensed that the Probe had slowed to near the speed of sound, electric pulses fired explosive bolts. Cut in half, the heat shield fell away and a small parachute opened. Finally moving only a few hundred miles per hour, the Probe extended its scientific instruments and began sensing the environment at the top of Saturn's chilly troposphere.

Thermometers and barometers measured temperature and pressure, while the accelerometer continued to monitor the slow descent of the probe and felt for surges of turbulence in the clear air. A small valve opened and gases began to move through tubes into the mass spectrometer and gas chromatograph. These devices measured the composition of the gases and the isotopic makeup of their elements. A third instrument precisely measured the fraction of helium present in the dominantly hydrogen atmosphere.

As it continued its descent, a radiometer sensed and measured the sunlight streaming down into the atmosphere, the heat coming out from the planet below, and reflections from cloud and haze particles. Using the same coil that had earlier measured the magnetic field, a small radio receiver listened for the crackle of distant lightning, while a lead-glass eye watched for flashes from nearby storms.

At first, in the chilly top of the troposphere — where the temperature was just 90 Kelvins above absolute zero (-300° F) — the instruments saw only a thin haze of ammonia-ice crystals. Then, with pressure and temperature rising, the Probe fell into a thick cloud of frozen ammonia and passed briefly through a stinging rain of liquid ammonia. Light levels dropped and turbulence buffeted the falling Probe. Passing safely outside Saturn's rings, the Orbiter was catching the Probe's whispery transmissions and sending them back to Earth.

The Probe's descent slowed as the air thickened. When the pressure passed one Earth atmosphere, electrical relays sent power to a small coil of wire wrapped around the parachute lines; they melted and the Probe once again dropped free. It fell through the nearly clear air into another cloud deck, this one of water ice. Temperature and pressure continued to rise, melting the ice to a thin wet film of acrid rain.

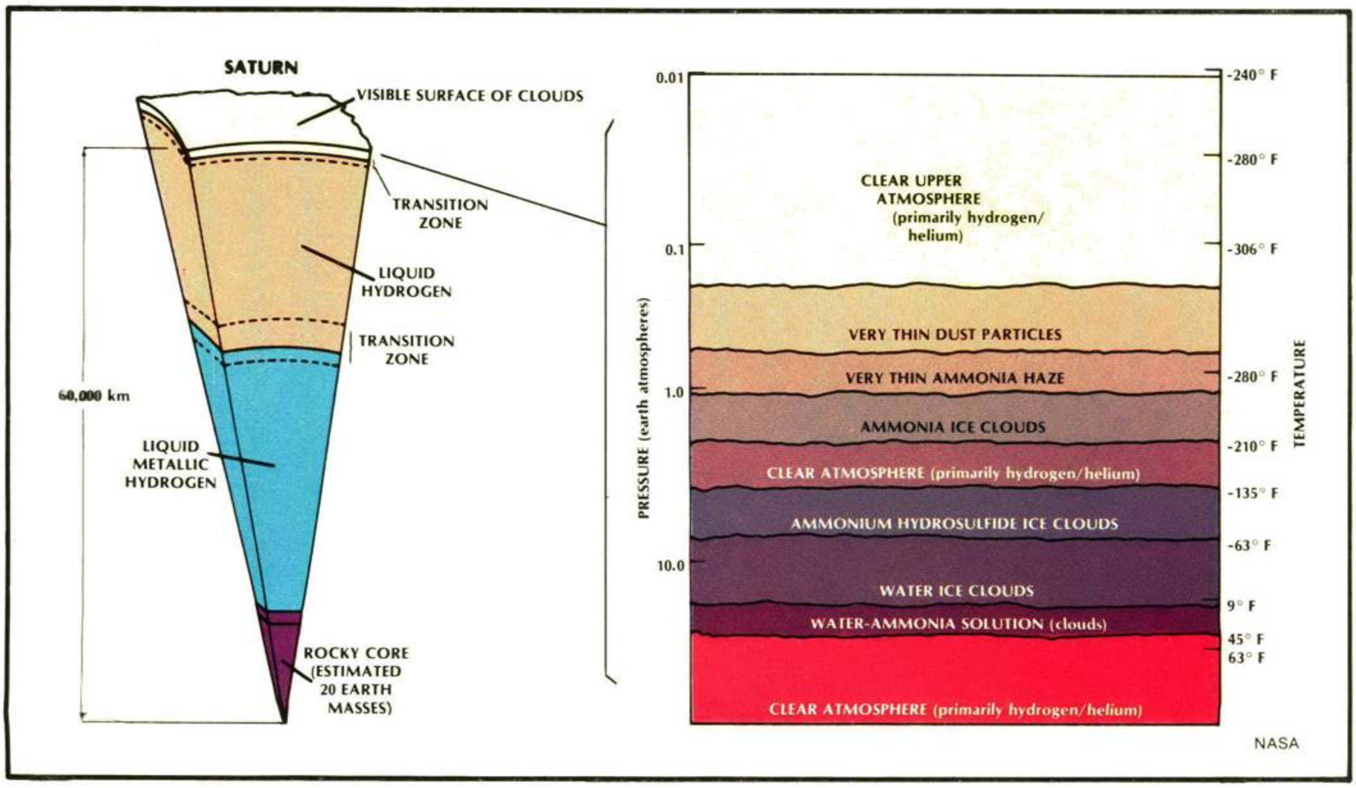
The sky was now nearly black; little sunlight could pass through the dense cloud decks. The faint radio signals reaching the Orbiter started to fade as the gases above the Probe absorbed them. The rain evaporated and the temperature rose steadily as the Probe fell deep into the atmosphere. The temperature passed 350 Kelvins (170° F) and the overheated electronics began to fail. Finally, the transmitter shorted out and the dead Probe, now silent, fell toward destruction in the hot black depths of the atmosphere.

Overhead, the Orbiter fired a rocket engine and slowed to begin its first orbit of Saturn. The year was 1992...

* * *

Pioneer 11 (renamed Pioneer Saturn) made the first flyby of the planet in September 1979. By August 1981, when Voyagers 1 and 2 will have completed their flybys, our reconnaissance of the saturnian system will be finished. We will have far more knowledge of Saturn, its rings, moons, and magnetosphere than we do now, yet many crucial questions will still be unanswered.

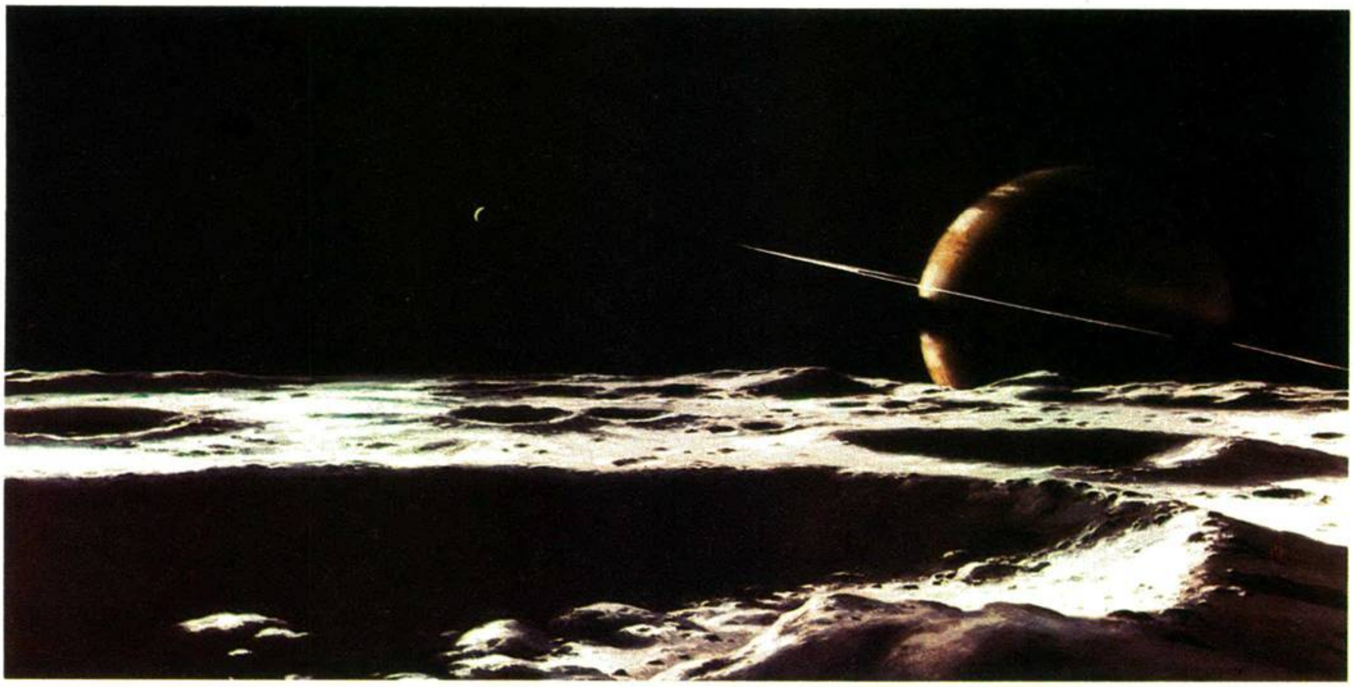
Only a probe into Saturn's atmosphere can determine its full composition, study the structure and physics of its clouds, and explore the atmosphere below them. Only an orbiter can watch the slow changes in the belts and zones of clouds, and monitor the changing illumination and temperature of the rings as Saturn moves through its seven-year-long seasons. Only an orbiter can systematically map the surfaces of the moons at high resolution, far beyond the


SATURN
VISIBLE SURFACE OF CLOUDS
TRANSITION ZONE
LIQUID HYDROGEN
TRANSITION ZONE
60,000 km
LIQUID METALLIC HYDROGEN
ROCKY CORE (ESTIMATED 20 EARTH MASSES)
PRESSURE (earth atmospheres)
0.01
0.1
1.0
10.0
CLEAR UPPER ATMOSPHERE (primarily hydrogen/helium)
VERY THIN DUST PARTICLES
VERY THIN AMMONIA HAZE
AMMONIA ICE CLOUDS
CLEAR ATMOSPHERE (primarily hydrogen/helium)
AMMONIUM HYDROSULFIDE ICE CLOUDS
WATER ICE CLOUDS
WATER-AMMONIA SOLUTION (clouds)
CLEAR ATMOSPHERE (primarily hydrogen/helium)
-240° F
-280° F
-306° F
-280° F
-210° F
-135° F
-63° F
9° F
45° F
63° F
TEMPERATURE

NASA

brief glimpses from Voyager, and watch sluggish weather systems move in Titan's mysterious atmosphere. In addition, the orbiter could carry a second probe, one to profile Titan's atmosphere and operate on the surface for months.

Finally, only an orbiter can observe the constant variations of Saturn's invisible magnetosphere, and determine the orbits and compositions of dust particles. All of these investigations could be carried out by the Saturn Orbiter Dual Probe (SOP^2) mission, currently under study by NASA. (Already in the works is the Galileo mission to Jupiter, a similar mission that will soon provide a tantalizing taste of what awaits us at Saturn.)



Saturn from Rhea. NASA painting by Ludek Pesek.

If SOP^2 were funded within the next two or three years, it could be launched in 1987 to reach Saturn in the early 1990s. There, it would drop probes into the atmospheres of Saturn and Titan, and orbit Saturn for years. This mission, a natural follow-on to the reconnaissance by Pioneer and the Voyagers, would systematically explore the system.

The Fundamental Saturn

But what do we know now, on the eve of the Voyagers' encounters, about the origin and history of the Saturn system? To basics, then: Saturn is one of the four gas giant planets, composed mostly (about 90%) of hydrogen and helium, plus 10% or so of ammonia, methane and water vapor, and only a small amount of the rocky materials that form the terrestrial planets. Largely gaseous, Saturn has no solid surface. It's a planet made almost wholly of weather. Circling it are the spectacular ring system (mostly frozen chunks of water ice) and a set of small moons in very regular orbits. Water-ice and rock probably make up the innermost moons. Farther outward orbits the giant, and probably rocky, moon Titan, its surface hidden by a deep atmosphere filled with reddish haze, and then beyond that swing the three outer moons that circle Saturn in irregular orbits.

Filling the space around Saturn and the inner moons hums the invisible magnetosphere: a region of ionized gas and radiation belts, shielded from the solar wind by Saturn's magnetic field and spun by the field's rotation into a maelstrom of particles and fields.

This varied and complex system brims with clues about its origin and history, if only we can only interpret them. Because hard facts about this distant system are few, much of our knowledge stems from theories and models, refined and adjusted until they seem to match observations. Pioneer, the Voyagers, and the SOP^2 will all test predictions made from these models.

Saturn contains about 95 times the mass of the Earth. Approximately 20 Earth masses reside in a core of ice and rock (probably molten); the remaining 75 Earth masses lie in a dense gaseous envelope/atmosphere of hydrogen and helium, containing about 1% ice and rock "impurities" dissolved in it. Saturn's 10-hour spin has flattened this atmosphere and distorts its gravity field from perfect spherical symmetry.

Since the amount and shape of the gravitational distortion depend on the distribution of mass inside the planet, analyzing the trajectories of probes can help astronomers study Saturn's interior. In addition, because the physics of a planet made of gas are far simpler than one made of rock, the same techniques used to model the evolution of stars can be used to model the evolution of Saturn. New observations can be compared with predictions made from the models. Measurements made by Pioneer of the gravity field, for example, fitted the model predictions well and are being used to refine its details.

Saturnigenesis

The Saturn system first took shape in the early solar nebula, a rotating cloud of gas and dust born in the collapse of an interstellar cloud. Astrophysicists have concocted two opposing theories to explain how Saturn formed from this cloud and separated into its core and envelope: one claiming that the core formed first and the envelope accumulated around it, the other calling for a concentration of gas in the nebula with the core taking shape as it collapsed.

In the first theory, ices and rock would have condensed in the cold outer parts of the nebula. They would then accrete stickily into kilometer-size snowballs becoming finally objects the size of small moons. The largest of these would grow by "eating" the others through collisions, eventually forming a planet perhaps 15 times the mass of the

Earth.

When the core grew past a certain mass, its gravity would actively capture the gas from the surrounding parts of the nebula. The proto-Saturn would grow by accreting hydrogen and helium until the newborn Sun blew away the nebular material.

In the second theory, a local concentration of gas and dust, formed by random collisions in the turbulent nebula, would have enough mass to begin collapsing — slowly — under its own gravity. Starting from a radius of some 120 million kilometers (2,000 times Saturn's present size), the protoplanet would take a few million years in this slow contraction phase. Gravitational compression would warm its center, and perhaps sometime during this phase the condensed ices and rock grains would melt, combine into drops, and settle toward the center of the protoplanet, forming a core.

When the temperature near the center of the growing protoplanet reached 2500 Kelvins, the heat and absorbed energy would tear apart all the hydrogen molecules. This process would steal energy — energy from the gravitational contraction — that was needed to heat the core and provide pressure to support the overlying layers. The consequences would be dramatic.

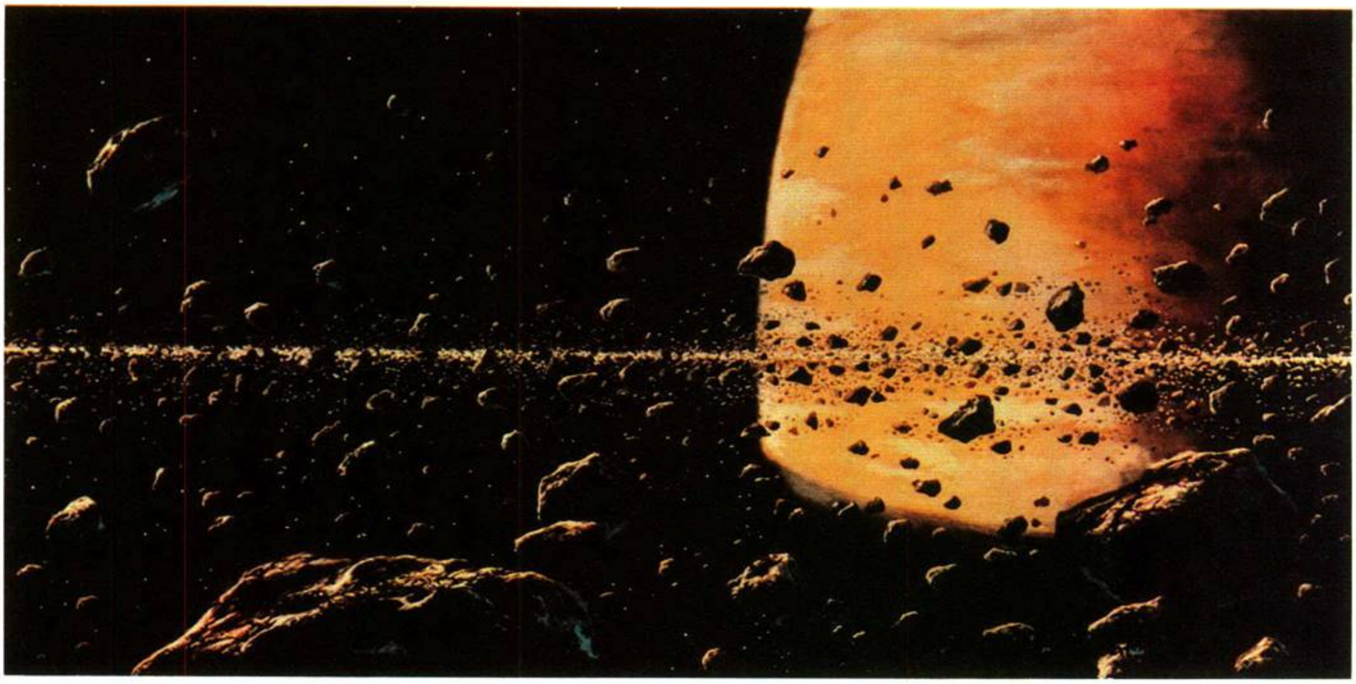
Starting with a size of roughly 40 times that of present-day Saturn, the protoplanet would collapse in only a couple of years to a few times the size we see today. Most of the hydrogen would be broken into separate atoms, some of it near the center crushed into the metallic phase hydrogen adopts under extreme pressures.

Red-Hot Saturn

The tremendous heat released by the collapse would make the proto-Saturn glow a dull red for a few million years. Then it would cool and shrink, rapidly at first and then more and more slowly, until after 4½ billion years Saturn reached its present size and temperature. Regardless of which theory is closest to what really happened, the evolution they predict from the late stages of collapse to the present is essentially identical.

Today — 4½ billion years after its birth — Saturn is still cooling off and shrinking. The planet radiates out into space roughly twice the amount of heat it absorbs from sunlight. Jupiter does this too and in its case, the amount is close to that predicted by theory. But with Saturn, the simple preliminary models call for significantly less heat than we actually see. What's wrong?

Calculations by D. G. Stevenson indicate that as Saturn's interior cooled below 8000 Kelvins (about a billion years after formation) helium would have separated out of the metallic hydrogen near the core and "rained" down towards the center. The heat released by the process could account for the excess heat radiating from the planet. According to this more sophisticated theory, Jupiter is still too hot inside for such a process to happen.



Saturn from within the rings. NASA painting by Ludek Pesek.

Some corroborating evidence came from the Pioneer flyby. Pioneer found that the axis of Saturn's magnetic field lies nearly parallel to its rotation axis. All other planets with magnetic fields have them tilted relative to the rotation axes. The dynamo theories of magnetic field generation all seem to require such a tilt relative to the spin axis. Dr. Stephenson analyzed the effect of helium rain-out on the fluid flows that generate the magnetic field. He concluded that the flow pattern produced by the helium separation could force the magnetic field axis to parallel Saturn's spin axis.

Where Did the Moons Come From?

The rapid whirl of a contracting proto-Saturn should have spun its outer regions into a disk that would have attracted infalling material also. The inner moons of Saturn probably formed in the midst of such a disk, while the outer ones may already have been present.

Phoebe, the small outermost moon, orbits Saturn in an eccentric, tilted, retrograde orbit (opposite the direction in which Saturn rotates). Jupiter has two sets of small moons in similar orbits, one set retrograde, one posigrade. Neptune has one small irregular satellite. Their orbital properties lead astronomers to think that these moons were captured. James Pollack suggested that capture might have occurred just before the protoplanet's final collapse. Objects passing through the tenuous outer parts of the protoplanet would slow down with some being captured into orbits. Moons caught well before the final collapse would orbit too long in the extended outer gassy layers. They'd lose their velocity and spiral inward to destruction, adding to the protoplanet's growing core.

But a moon captured just before or during the collapse would have the planet collapse out from under it, so to speak, leaving it in a stable orbit. Phoebe, and perhaps Iapetus and Hyperion (Saturn's other irregular satellites), may be such pre-planetary objects, captured from the solar nebula. If so, they could preserve a unique record of conditions in the early solar nebula.

Deeper in, Titan and the inner moons must have formed after the collapsing protoplanet had shrunk past their orbits. Because of proto-Saturn's radiating heat, materials of the disk would likely be too warm for some ices (methane, ammonia, water) to condense — though at Titan's orbit, some methane must have condensed for we can see it in the moon's atmosphere.

Closer still to Saturn, ice and rock will have condensed in differing proportions at different distances. We see this effect in the jovian system: there, the proportion of ice in each of the four large moons increases with distance from Jupiter. We can expect Saturn's innermost moons to be rockier than the outer ones. Images from Pioneer of the moon 1979 S1, which orbits just outside the rings, suggest that it may have a dark surface unlike the other inner moons.

The proportions of ice and rock in a moon can be found by measuring its diameter and mass; these yield the moon's density. Ice has a density near 1.0, while a density of at least 2.9 indicates rock. The Voyagers will examine the densities of several moons as they whiz through the system, but until we have long-term studies with an orbiter, we will not get accurate values for all of them.

Whence the Rings?

Saturn's rings should also provide clues to the early history of Saturn, unless they are the remains of a moon that passed too close and was broken up by tidal forces. The generally preferred theory calls for the rings to form (together with the inner satellites) as a condensation of materials in a disk extending out from the equator of the protoplanet. If this inner disk material was once part of proto-Saturn's atmosphere, then the rocky silicate grains may have settled out into the protoplanet, leaving water ice to condense later in the rings — which fits what we see there today.

The same process might also have affected the innermost moons. A transition region in the disk could have existed. Outward from it, most matter would lie outside the protoplanet's envelope; inward, material was "processed" by proto-Saturn's atmospheric envelope. Planetary scientists won't resolve all these conflicting possibilities with the data from the Voyagers.

In the far infrared portion of the spectrum, at wavelengths around one millimeter, the centimeter-size particles making up most of the rings are partially transparent. Observations in this part of the spectrum should tell us what the interiors of the ring particles are like, and if their composition varies outward from Saturn. Voyager doesn't carry an instrument to examine this, but it has been proposed that the SOP^2 mission carry one. Additionally, millimeter infrared sensing will allow us to study the temperatures and compositions of Saturn's and Titan's atmospheres and maybe observe Titan's surface.

The tumultuous birth of Saturn and its system probably took only about 100 million years in all. For another half billion years, asteroids and comets in unstable orbits battered the surfaces of the moons, as they did in the jovian system and among the terrestrial planets. Once the crater-making population of objects had been exhausted (excepting the odd impact from a stray comet or asteroid), the history of the Saturn system must have settled down and become pretty uneventful.

Orbits Built for Two...

But the system of moons contains surprises still! Observations by Pioneer of the saturnian radiation belts showed gaps in them where moons were absorbing the radiation. Other gaps exist where moons haven't yet been found, and the previously unknown moon, 1979 S1, was discovered by Pioneer in one of the gaps.

Observations from Earth in late 1979 and early 1980, taken while the rings were edge-on to our view and nearly invisible, revealed several new small moons. The surprise is that some of these objects appear to be sharing orbits.

One or two moonlets may share the orbit of Dione, precariously balanced in the semi-stable orbital positions called Lagrangian points. Another mini-moon may share 1979 S1's orbit, and recent analysis of the radiation data suggests yet another may share the orbit of Mimas. If these reports are confirmed, it seems that Saturn has more moons in its inner system than independent orbits to house them. (Only one other case of orbit-sharing is known in the entire solar system: the Trojan asteroids which oscillate around the L-4 and L-5 points in Jupiter's orbit.)

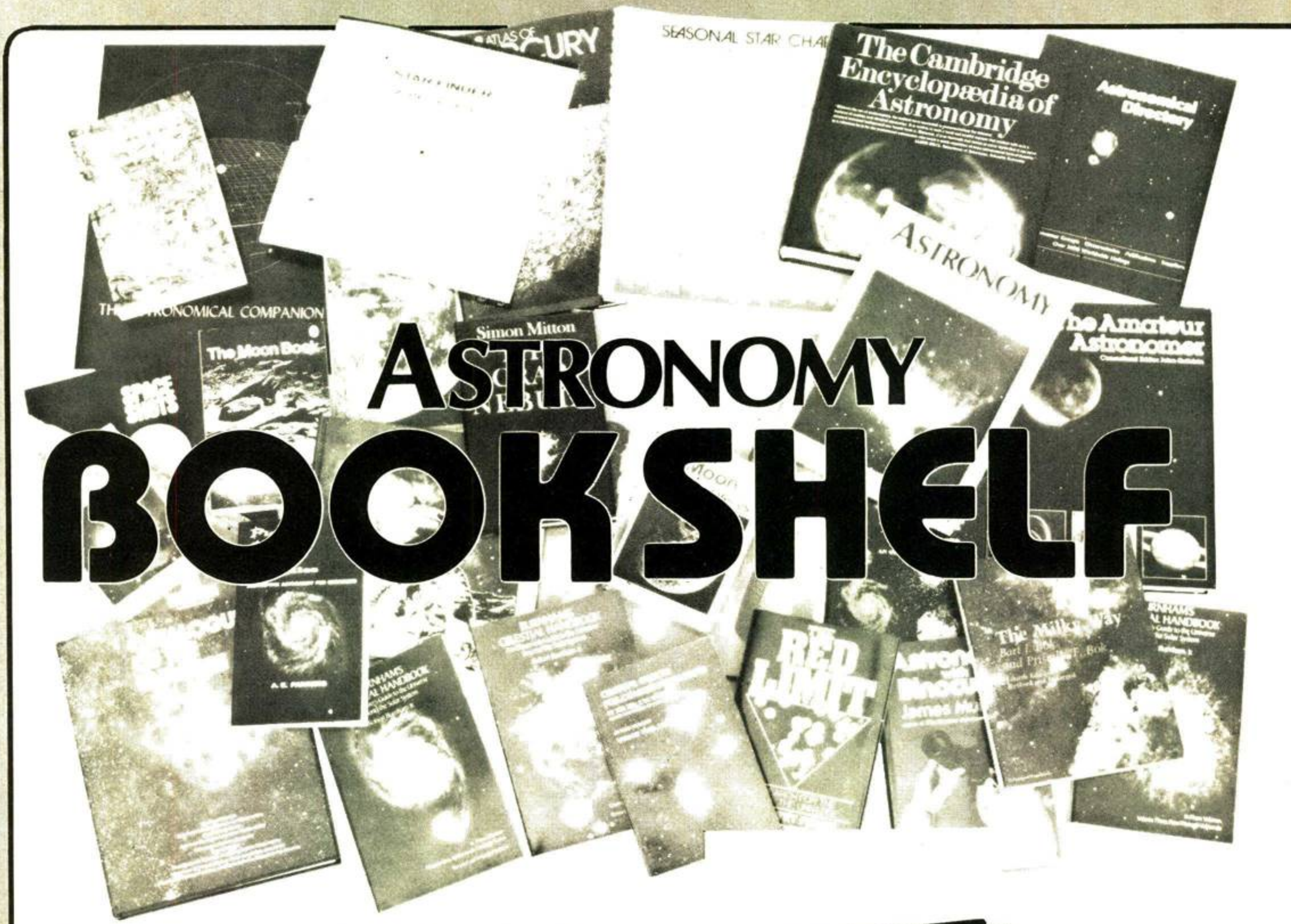
Objects held at Lagrangian orbital points are not trapped there very strongly. An impact with a large asteroid, or even tidal effects from another moon, might suffice to eject a small moon into another orbit. After ejection, the moonlet might even collide with the other moon. Three probable fates await such a "rogue" moon: 1) it could be ejected from the satellite system altogether, 2) it could approach too close to Saturn and be broken up to join the rings, or 3) it could collide with another moon. Recapture into another stable orbit or Lagrangian point is very unlikely, so the most common fate is probably collision with another moon.

The results of such a collision would be spectacular and probably unmistakable. Collisions between small moons would be at much lower speeds than the impact of passing asteroids and comets. The larger of the two might fracture or deform, while the smaller would crush and splatter. (If relative velocities were slow enough, the two might hit and stick.) A lot of ice would be melted, the liquid spreading across the surface in a sheet with unmelted fragments (icebergs!) floating in it before it froze. Collisions between somewhat larger objects might generate so much melting as to resurface the moon entirely with ice.

But how likely is all this? Is it just agile theorizing or is there any example suggesting it may have happened? Iapetus, the largest of the outer irregular moons, has one hemisphere that reflects six times as much sunlight as the other — a record for the entire solar system. No totally convincing explanation for this asymmetry has yet been proposed — despite a very intriguing idea put forth by Arthur C. Clarke in the book *2001: A Space Odyssey*. Although we are probably seeing the scar of a satellite collision with Iapetus, unfortunately the two Voyagers won't approach it closely enough for confirmation, and their best pictures will show few details. Again, a Saturn orbiting mission is needed to image Iapetus clearly and, we hope, resolve the mystery.

While we know a good deal now, even before Voyagers 1 and 2 reach Saturn, many questions about the Saturn system and its history await their data. Afterward, the need for the Saturn Orbiter Dual Probe mission will seem even greater — to explore in detail the many strange and wonderful worlds glimpsed by the Voyagers and to answer the questions that we now don't even know enough to ask.

Edwin Strickland is currently completing his work for the Ph.D. degree in planetary geology at Washington University in St. Louis, Missouri. His research work uses digital image processing techniques applied to photos from planetary probes. He has a general interest in planetary evolution and is betting that Voyager 1 will show evidence of collisions among the saturnian satellites. His last article for ASTRONOMY was "The Colors of Mars" in the May 1980 issue.



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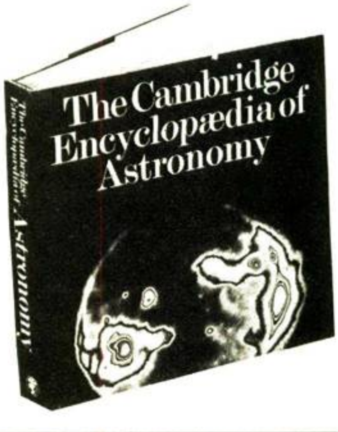

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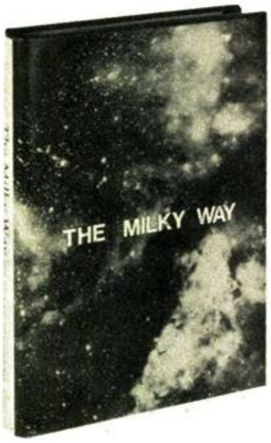

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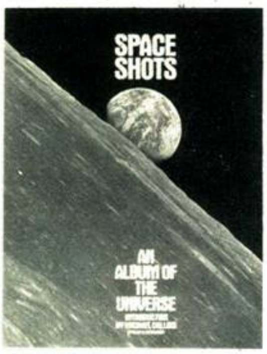

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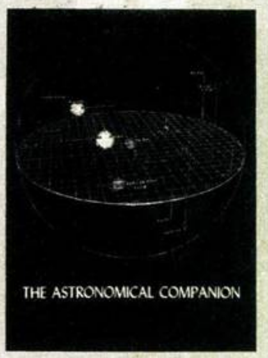

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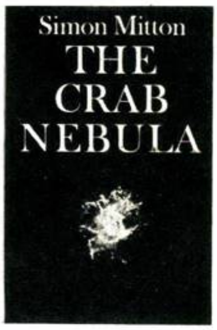

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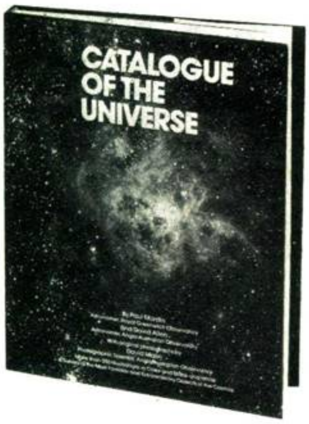

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Atlas of Mercury, Moore & Cross Fine maps and Mariner 10 photos of the little planet; also text with facts, historical and scientific, about it. Hardcover, $10.75.

The Amateur Astronomer, Rukl A compendium of useful knowledge for any observer, this book also tells you where to look to find the naked-eye planets from 1979 to 2000. Eclipses and lunar phases, too! Hardcover, $10.50.

The Big Bang, Silk How the universe began and how it has evolved over the eons: the intriguing and at times bizarre story of cosmology. Paperback, $9.50.

through the eyepiece

close-up on pegasus

November's most striking events occur in the morning sky during roughly the first half of the month: you'll see a wonderful array of planets and stars! In addition, Jupiter and Saturn rejoin the observing fold, the Leonid meteors return, and three periodic comets are visible. What more could you ask for?

Mercury

Mercury passes between the Sun and Earth at 9^h UT on November 3rd; this is called inferior conjunction. It means that Mercury switches from being an evening object to a morning one — though a week will pass before it becomes relatively easy to see. Look on p. 105 for a diagram of its motions in the eastern sky before sunrise.

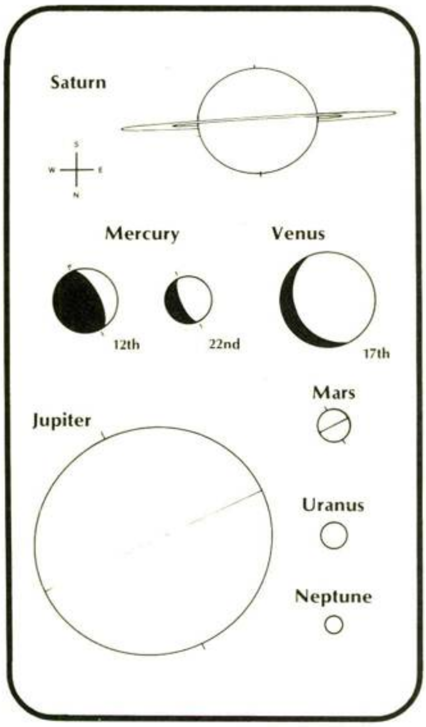
Mercury's rapid rise up away from the horizon means that the changes in its telescopically visible phases will happen quickly, too. On the 7th, it is 5% illuminated; this grows to 25% by the 12th, and 50% by the 19th, when it simultaneously reaches greatest western elongation and highest elevation. Through a telescope it will then look like a featureless First Quarter Moon, just 10 seconds of arc in diameter. Around this time also, it'll join a conspicuous grouping of Venus, Jupiter, Saturn, and Spica (see below).

During the rest of November it will sink down toward the horizon more slowly than it rose, finally disappearing into the horizon murk around the middle of December. At the end of December, Mercury reaches superior conjunction; its next appearance will be in the evening sky, early in the new year.

Venus

Brilliant Venus, the brightest of the planets, has three conjunctions this month: with Saturn on the 3rd (at 21:55 UT), the Moon on the 4th (10:55 UT), and Spica (Alpha Virginis) on the 17th (13:43 UT). All three are part of a very interesting show in the morning sky.

If you go out and look east 45 minutes before sunrise on the 3rd, you'll see Venus a degree below Saturn; their magnitudes are -3.5 and +1.2, respectively. (At this time, they are not yet in conjunction — that happens about 10 hours later.) Jupiter (magnitude -1.4) lies 5° to the upper right of Venus, and Spica (+0.9 mag.) is about 17° below it. Off to the left gleams ruddy, -0.1 magnitude Arcturus. A waning crescent Moon, 25 days old, lies about 6° above Jupiter. (By the way, Jupiter and the Moon will be in conjunction at 1:25 UT on the 4th, the Moon passing 2° 36′ north of Jupiter.)



On the following morning, the only change visible to the naked eye is in the Moon, which lies now to the left of and close by the Venus-Saturn pair. All the others will appear in the same relative places. If you live on the east coast, conjunction between the Moon and Venus (separation 2° 19′) is happening just about the time you are watching.

Two weeks later, on the 17th, Venus will "conjunct" with Spica. This time the Moon will be absent — it's now nearing Full — and the starry background of Spica and Arcturus will have risen higher. Mercury, too, will have popped into sight to the left and below. The actual time of conjunction comes around sunrise for the middle of the continent, when the separation is a little over 4°.

Photographers take note: any lens of 35 mm focal length or shorter (in 35 mm format) is ideal for capturing the full array of planets, stars, and Moon on one frame....

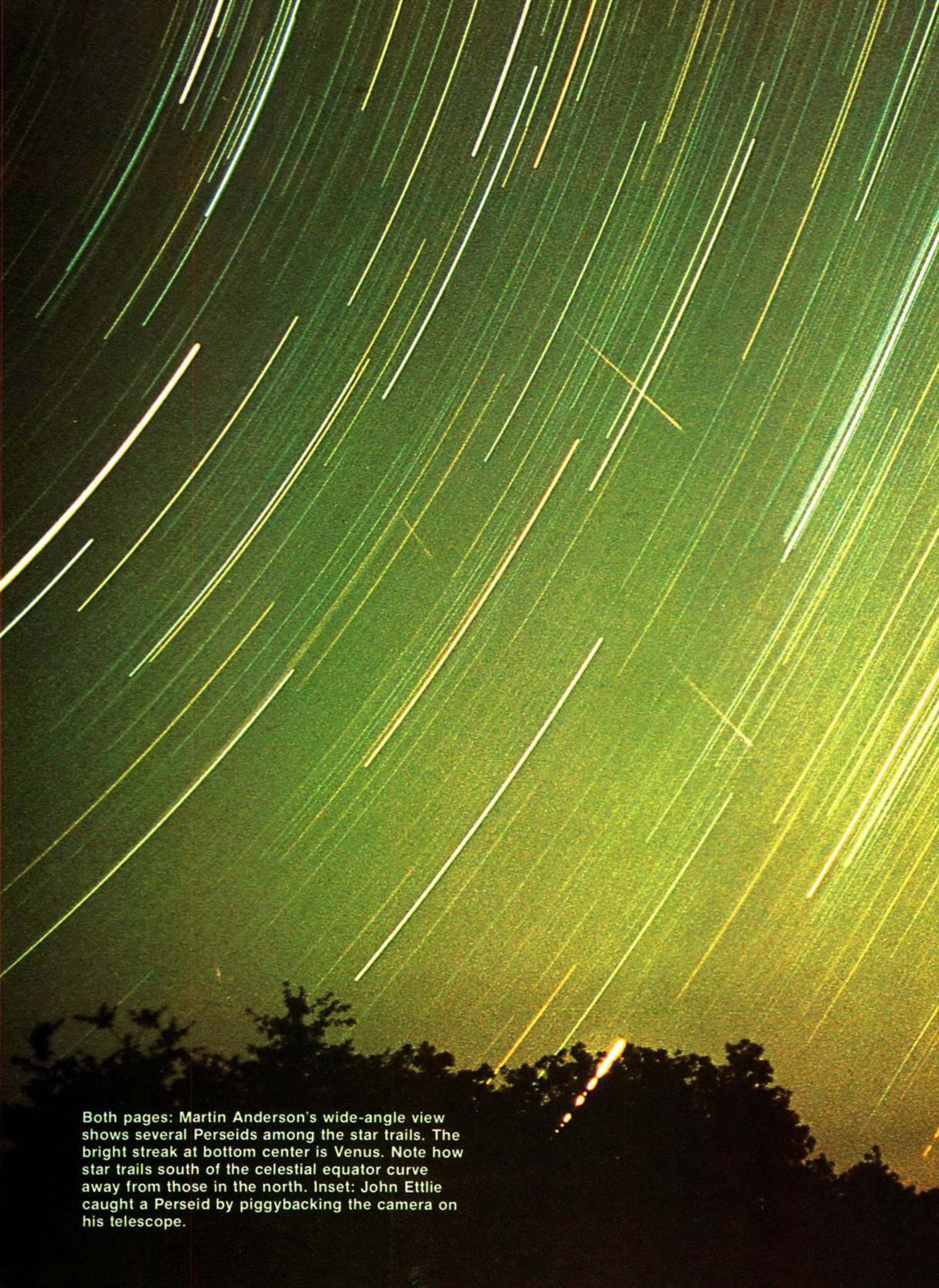
Moon

The most visually spectacular of the Moon's conjunctions are listed above in the Venus section, but on November 10th there's an interesting "triple conjunction" involving Mars, Neptune, and a 3-day-old Moon.

The sequence goes as follows: at 12:34 UT, Mars overtakes Neptune, passing 2° 18′ south of it. At 18:47 UT, the Moon passes north of Neptune, missing it by 2° 47′; then 24 minutes later, the Moon sweeps by 5° 3′ north of Mars.

The problem is that the actual time of conjunction isn't very convenient for observations from North America. The first of the three you'd have to watch during daylight and the last two occur in a rather bright twilight sky. Low-powered scanning with an RFT or

At 5:30 a.m. on the morning of March 7th, 1976, Comet West and its stellar neighbor Enif (Epsilon Pegasi) were reflected in Carnegie Lake, Princeton, New Jersey. Robert E. Flory used a 4-second exposure on 200 ASA slide film with a 50 mm lens set at f/1.4. This wins the "Best Astro-Photo" competition for November.



Both pages: Martin Anderson's wide-angle view shows several Perseids among the star trails. The bright streak at bottom center is Venus. Note how star trails south of the celestial equator curve away from those in the north. Inset: John Ettlie caught a Perseid by piggybacking the camera on his telescope.

binoculars will work best to locate the objects: 45 minutes after sunset on the 10th, the Moon is 13° high in azimuth 229°, Mars 9° at 227°, and Neptune 11° at 229°. Mars is at magnitude +1.5, Neptune +7.8.

On the 1st and the 28th, Regulus (Alpha Leonis) is occulted, but neither will be seen as an occultation by most North American observers. The southern limit for the occultation on the 1st runs east/west roughly along the 48° parallel of latitude. This places most of the U.S. (as well as southern Ontario) too far south to see the occultation — instead the Moon slips past the star, to the north. The event begins in the west at 9:43 UT and ends in the east at 10:53 UT.

The occultation on the 28th is a daylight event for the westernmost part of the continent and will therefore be difficult to observe. Disappearance happens at 18:49 in Edmonton, 18:59 in Vancouver, 19:15 in south-central Oregon, and 19:34 in central California. Since the Moon's phase in both occultations is near Last Quarter, disappearances are on the bright limb.

At 22^{h}UT on the 22nd, the Moon, just past Full, will pass about a degree north of Aldebaran (Alpha Tauri) in the Hyades cluster. Take a look in the east as the Moon rises where you live; binoculars may be necessary to make out the star.

Mars

Mars spends the entire month at virtually the same position in the evening sky: about 9° high in azimuth 228°, 45 minutes after sunset. This is very low; you'll need an unobstructed southwestern view if you want to catch sight of it.

Asteroids

You can find 1 Ceres at $7^{h}57^{m}30^{s}$, 24° 43′ 57″ on the 15th. It is a magnitude 7.0 dot of light in Canis Minor/Gemini, a region that rises around 10 p.m. local time.

On November 15th, 2 Pallas lies in the Cetus/Fornax area at $2^{h}06^{m}21^{s}$, -25° 20′ 10″. It has a brightness of magnitude 7.8, and transits the meridian around 10 p.m. local time.

Look in the Virgo region at $13^{h}03^{m}17^{s}$, -3° 49′ 57″ on the 15th for 10.8 magnitude 3 Juno. This part of the sky, just to the northwest of Spica, rises about 4:30 a.m. local time.

4 Vesta, at $10^{h}16^{m}04^{s}$, 13° 57′ 52″ on the 15th, is a magnitude 7.4 object in Leo. It transits the meridian about 6:30 a.m. local time.

(All asteroid coordinates given above are for the epoch 1950.0.)

Jupiter

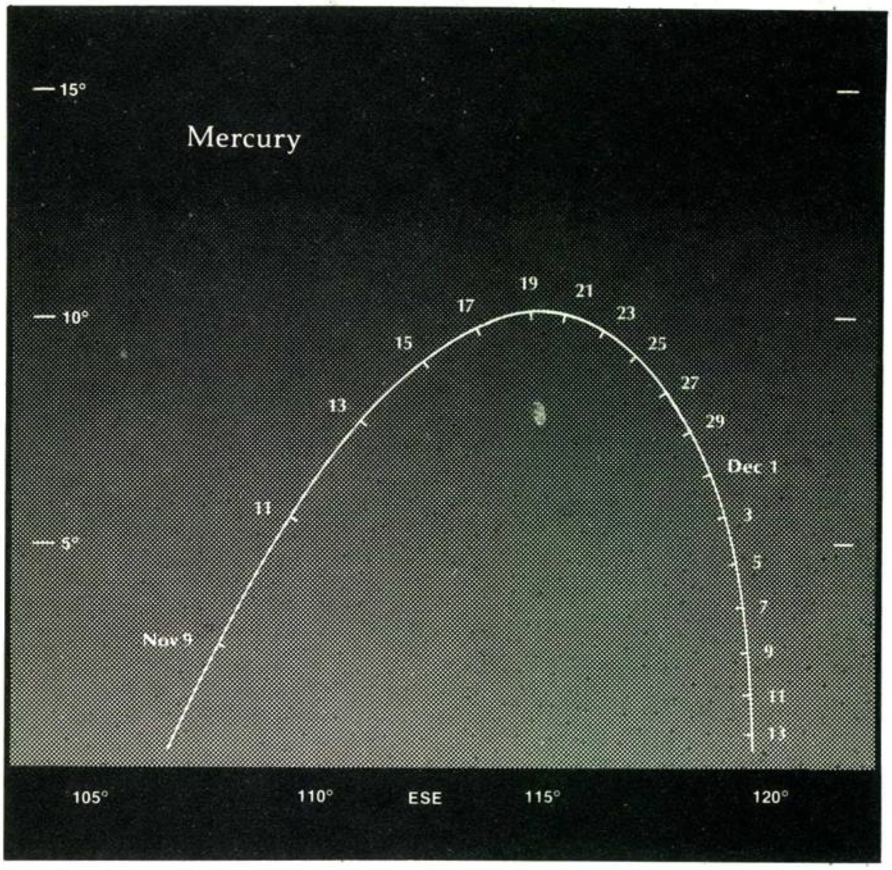
Jupiter, an outstanding participant in the morning-sky conjunctions (see section on Venus), has also become a target for telescopists once again — even if the time of night is inconvenient: on the first of November it rises around 4:15 local time; this drops back to 2:15 by the end of the month.

Its apparent equatorial diameter is 32.7 seconds of arc at mid-month (polar diameter is 30.5″); the planet lies just over six astronomical units away. To an observer at Jupiter, Earth would be almost 8° to the east of the Sun.

If you're like most observers, this month you'll be getting your first good views of Jupiter after a break of two months or so. You'll probably find you have to recondition your eye to recognize jovian "surface" details again. Of course, the two main equatorial belts pop into view immediately, but discerning all those variegated knots, whorls, and streaks of color you could see by the end of the last apparition will take a little practice. Don't be concerned: just fit Jupiter back into your regular observation schedule and in no time you'll be back in top form.

Saturn

Like Jupiter, Saturn is in full view now, too. Both planets lie relatively close together in the sky, though this is just an optical effect: Saturn in reality is much more distant — by more than



Left: Streaking down toward the bowl of the Big Dipper, this Perseid flared out just a moment too soon! Photo by Mike Walters. This page: Mercury's path in the predawn sky is shown through mid-December. The time is 45 minutes before sunrise, the assumed latitude 40° north.

four astronomical units.

Through a telescope, it looks most like a diminutive, pallid copy of Jupiter, so much so that if it weren't for the rings, few observers would get very excited about it. Smaller, far less massive, and cooler than Jupiter (see Stellar Frontiers this month), Saturn lacks much of the cloud belt activity that's so appealing with Jupiter. As a result, careful watching for small details requires a larger telescope (8 to 10-inch is best as a minimum) and more practice than with Jupiter.

The rings themselves now look "upside down" in the eyepiece . We are looking onto the northern side of the rings (the same side Voyager 1 is seeing on its approach). Voyager is approaching Saturn 14° above the ring plane, the Earth is about 6° above the ring plane, and the Sun is somewhat lower still, about 4°.

Uranus

Uranus is in conjunction with the Sun on November 18th at 1^h UT. Moving into the morning sky, it won't be visible until well into December.

Neptune

Co-starring with Mars and the Moon in the "triple conjunction" on the evening of the 10th, Neptune offers very little else for the observer. It's small (2.3 seconds of arc), distant (over 31 AU away), and dim (magnitude 8).

Meteors

The main meteor event of November is the Leonid shower, which peaks on the evening of the 16th-17th. The radiant lies in the "Sickle" of Leo (the lion's head) and rises around 11:30 p.m. local time; the Moon, near First Quarter, will set an hour or so later. In short, conditions look pretty good for this year's display.

However, the vexed question of how strong the shower will be remains unanswered. It's a fact that at 33 year intervals, right after the stream's parent comet (Tempel-Tuttle) passes, the display reaches phenomenal numbers. The last such "storm" was in 1966, so the 1999 one should be spectacular. But this year? Who knows — go out and see!

Another meteor shower, less renowned but probably numerically equal in the average year, is the Taurid. Actually comprising two streams, the southern and the northern, it has an hourly rate of 10 to 15. The "peak" of activity is rather diffuse, running from the 3rd of November for the next 10 nights. The radiant lies to the southwest of the Pleiades. The stream produces bright meteors and fireballs, but the Moon, at Last Quarter, will interfere a lot.

Comets

Three periodic comets will be visible in the late fall and early winter this year: Comets Encke (3.3 year period), Stephan-Oterma (38 year period), and Tuttle (14 year period). All are telescopic, as their magnitudes show, and the coordinates given are for epoch 1950.0, so you can plot their positions on a star atlas.

Comet Encke

Oct. 18: 7h 7m, +59° 51′ (magnitude 9.3); **Oct. 23**: 9h 15m, +60° 14′ (8.5); **Oct. 28**: 11h 22m, +51° 21′ (7.7); **Nov. 2**: 12h 41m, +35° 25′ (7.5); **Nov. 7**: 13h 26m, +21° 56′ (7.2); **Nov. 12**: 13h 53m, +10° 29′ (7.1); **Nov. 17**: 14h 13m, +1° 50′ (7.1); **Nov. 22**: 14h 29m, -4° 54′ (7.2); **Nov. 27**: 14h 46m, -10° 29′ (7.3); **Dec. 2**: 15h 6m, -15° 23′ (7.5); **Dec. 7**: 15h 32m, -19° 42′ (7.8).

Comet Stephan-Oterma

Nov. 7: 5h 19m, +8° 46′ (10.4); **Nov. 12**: 5h 23m, +10° 34′ (10.2); **Nov. 17**: 5h 26m, +12° 36′ (10.1); **Nov. 22**: 5h 28m, +14° 53′ (10.0); **Nov. 27**: 5h 30m, +17° 22′ (9.9); **Dec. 2**: 5h 31m, +20° 1′ (9.9); **Dec. 7**: 5h 31m, +22° 46′ (9.8); **Dec. 12**: 5h 31m, +25° 34′ (9.8); **Dec. 17**: 5h 31m, +28° 18′ (9.9); **Dec. 22**: 5h 31m, +30° 55′ (9.9); **Dec. 27**: 5h 32m, +33° 21′ (10.0).

Comet Tuttle

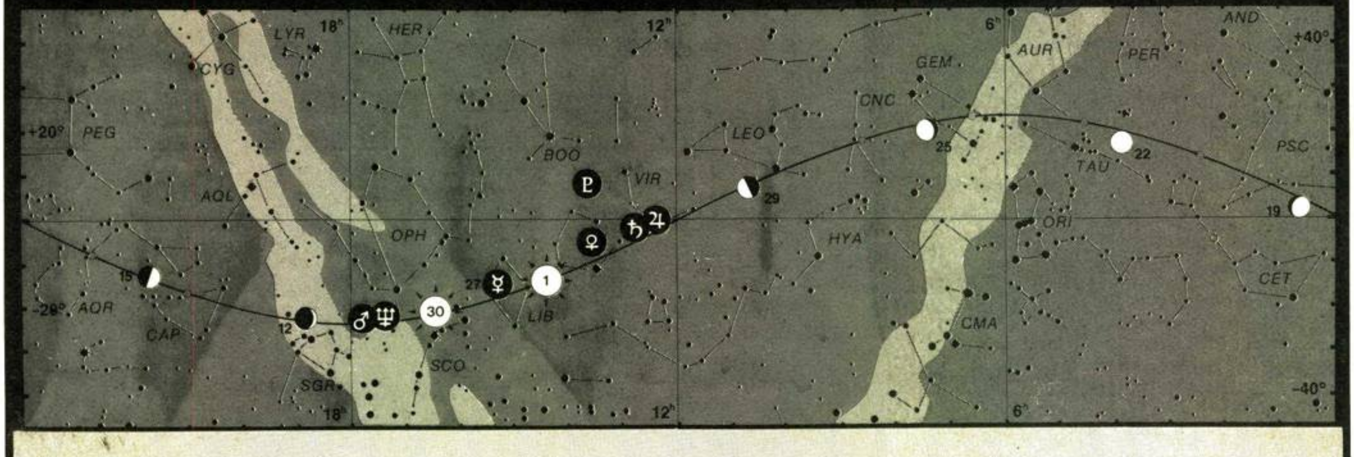
Nov. 7: 10h 7m, +37° 12′ (9.8); **Nov. 12**: 10h 16m, +30° 22′ (9.4); **Nov. 17**: 10h 24m, +22° 1′ (8.9); **Nov. 22**: 10h 32m, +11° 59′ (8.6); **Nov. 27**: 10h 40m, +0° 20′ (8.3); **Dec. 2**: 10h 48m, -12° 22′ (8.2); **Dec. 7**: 10h 57m, -25° 7′ (8.1); **Dec. 12**: 11h 6m, -36° 52′ (8.2); **Dec. 17**: 11h 17m, -47° 1′ (8.4); **Dec. 22**: 11h 28m, -55° 24′ (8.6); **Dec. 27**: 11h 42m, -62° 14′ (8.9).

close-up on pegasus

The Great Square of Pegasus is one of the better known asterisms in the sky, making the constellation easy to recognize. Actually, of course, only three of the four stars making up the Square properly belong to Pegasus, the fourth — Alpheratz — being Alpha (α) of the constellation Andromeda. Alpheratz was once thought of as being shared by both groups, and was given the additional designation of Delta (δ) Pegasi, but when the official constellation boundaries were assigned, it went to Andromeda — which explains why Pegasus today has no star designated Delta.

The large space enclosed by the Square, in which the ancient Babylonians located the Garden of Paradise, seems at first glance to be empty. But closer inspection shows it sprinkled with faint stars. The famed German observer Argelander saw 30 naked-eye objects inside the Square, while Schmidt, with the advantage of the clear skies of Greece, counted no less than 102. How many can you pick out from your favorite observing location? Be sure to wait for a transparent, moonless night!

planetary data november 1980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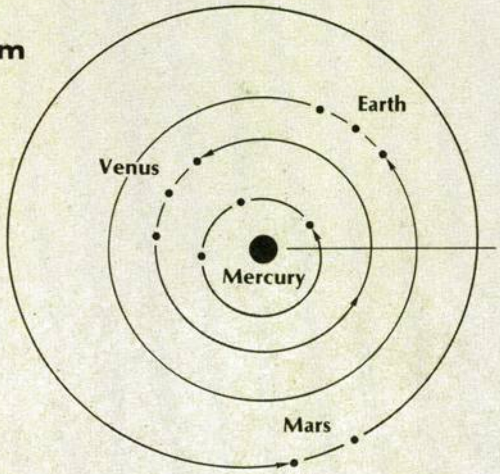
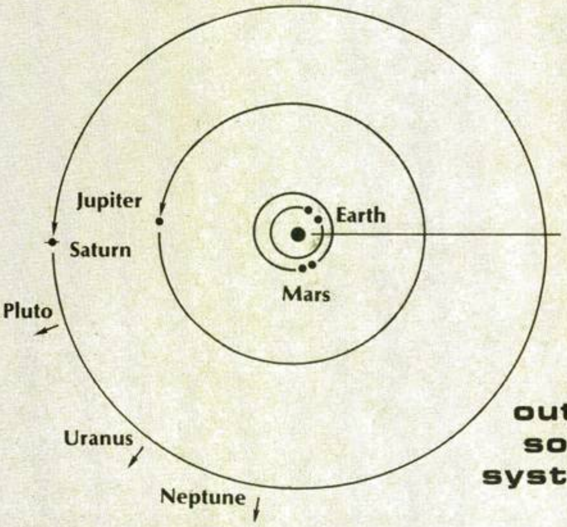
inner solar system


Earth
Venus
Mercury
Mars

outer solar system


Jupiter
Saturn
Earth
Mars
Pluto
Uranus
Neptune

				Angular	%	Distance (AU) from:		Longitude:		R.A. (1980.9) Dec	
		Date	Mag.	Size	Illum.	Earth	Sun	Heliocentric	Ecliptic		
Sun		10	--	32.3′	--	0.99	--	--	227°45.5′	15 01.1	-17°07.5′
		20	--	32.4′	--	0.99	--	--	237°50.0′	15 42.2	-19°40.6′
Mercury	☿	10	+1.1	7.6″	18%	0.76	0.31	81°58.9′	214°42.0′	14 11.4	-11°32.6′
		20	-0.3	6.6″	60%	1.01	0.34	141°01.5′	218°12.3′	14 27.0	-12°03.5′
		30	-0.5	5.5″	85%	1.22	0.40	185°47.9′	230°57.0′	15 17.2	-16°36.6′
Venus	♀	10	-3.5	13.4″	81%	1.25	0.72	140°29.9′	192°22.0′	12 49.7	-3°25.9′
		30	-3.5	12.3″	86%	1.36	0.72	172°59.0′	216°54.7′	14 22.3	-12°16.3
Mars	♂	15	+1.5	4.3″	97%	2.16	1.42	286°13.5′	264°15.7′	17 36.6	-24°21.0′
Jupiter	♃	15	-1.4	32.6″	100%	6.03	5.44	175°32.0′	183°01.3′	12 14.5	-0°19.7′
Saturn	♄	15	+1.2	16.4″	100%	10.17	9.52	181°59.9′	185°53.1′	12 26.6	-0°31.2′
Uranus	⛢	15	6.1	3.5″	--	19.77	30.09	235°49.9′	235°15.5′	15 33.6	-18°57.3′
Neptune	♆	15	8.0	2.3″	--	31.14	30.28	262°13.7′	260°54.9′	17 22.6	-21°51.1′
Pluto	♇	15	14.0	--	--	30.91	30.09	201°55.5′	202°28.1′	13 49.3	6°35.3′

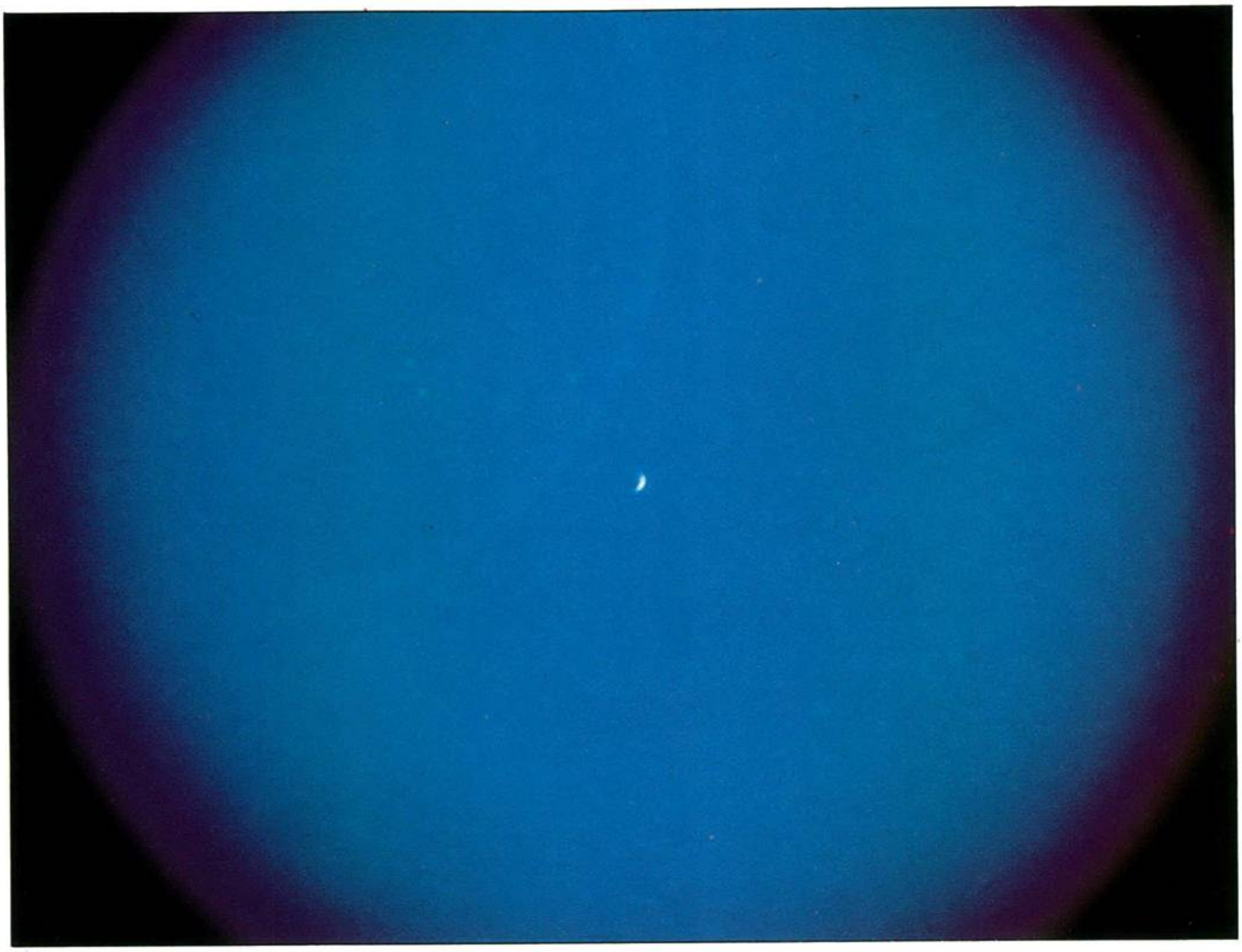
moon data

New Moon	November 7 at 20:43
First Quarter	November 15 at 15:47
Full Moon	November 22 at 06:39
Last Quarter	November 29 at 09:59
New Moon	December 7 at 14:35
First Quarter	December 15 at 01:47

Apogee: November 5 at 17h .. 406,422 km
Perigee: November 21 at 1h... 359,259 km

universal time

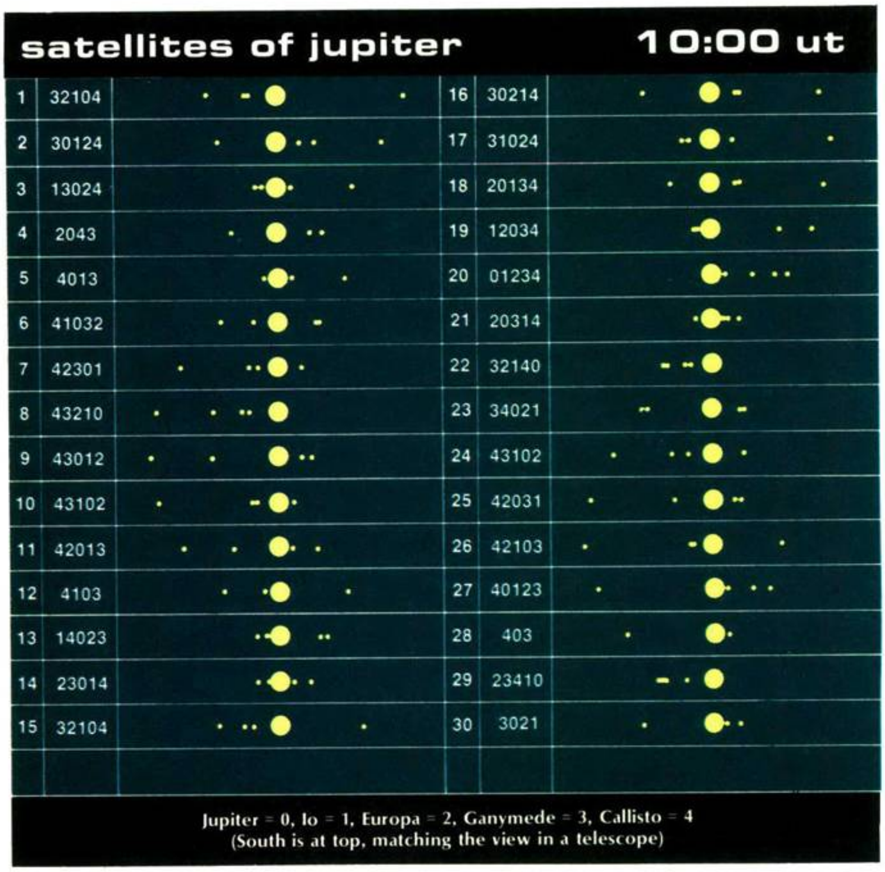
Astronomers the world over use an unambiguous system of time reckoning based on a 24 hour clock, called Universal Time (UT). Times in Through the Eyepiece are UT unless noted otherwise. To convert UT into your local standard time, subtract the following number of hours for each time zone: EST, 5; CST, 6; MST, 7; PST, 8; Alaska and Hawaii, 10. For example, if an event is to happen at 03:00 hours UT on Jan. 2, then the time in EST would be 10 p.m. Jan. 1. Likewise, 03:00 UT on March 5 becomes, in PST, 7 p.m. on March 4.



On July 9th, 1980, Venus was occulted by the Moon as seen from the southwestern U.S. Walter Taylor (of Fresno, California) photographed the pair before Venus was covered up. He used his 6" f/15 refractor and a 1/125-second exposure at the prime focus on 200 ASA slide film.

Despite its status as one of the largest constellations in the sky, Pegasus is surprisingly lacking in deep-sky objects of interest. The finest is without doubt the sixth-magnitude globular cluster **M-15**, easily located just 4° northwest of Enif (Epsilon [ϵ] Pegasi). A line from Theta (θ) Pegasi through Enif points directly at it, and it is easily picked up in binoculars or a finder. As Holyoke suggests, "Look for a fly on the nose of Pegasus."

Though smaller and less impressive than M-13, the Hercules Cluster, M-15 is nevertheless a grand object, and many consider it to be among the finest of all globulars. Even a four-inch telescope at 70 to 100x resolves its outer halo of stars with averted vision. A six-inch reflector at 100x or more shows glittering pinpoints of light all the way to its compact core. On dark tranquil nights, the view in 10 and 12-inch telescopes at 150 to 300x is simply fantastic.



satellites of jupiter 10:00 ut

1	32104	16	30214
2	30124	17	31024
3	13024	18	20134
4	2043	19	12034
5	4013	20	01234
6	41032	21	20314
7	42301	22	32140
8	43210	23	34021
9	43012	24	43102
10	43102	25	42031
11	42013	26	42103
12	4103	27	40123
13	14023	28	403
14	23014	29	23410
15	32104	30	3021

Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4
(South is at top, matching the view in a telescope)

M-35 and its more distant companion cluster NGC-2158 (below and to the left) are in Gemini. Photo by Sheldon Faworski. Overleaf left: NGC-891, a 12th magnitude edge-on spiral galaxy in Andromeda, clearly shows the dark lane of dust along its equator. Overleaf right: M-101, a face-on spiral galaxy in Ursa Major (north is at left). Both photos by Bill Iburg.

Epsilon (ε) **Pegasi**, also known as **Enif**, is a double star. This yellowish-orange, type K2 supergiant sun shines at magnitude 2.5 and has been suspected of variability by some observers. The primary has an 8.7 magnitude blue-violet companion about 143 seconds of arc away in position angle 321°, and there is also a faint 11th magnitude star at 82 seconds (position angle 325°), making this object an apparent triple system in medium apertures. In fact, there is no physical association.

Particularly suitable for binocular viewing, the widely separated apparent double **Pi^1** (π^1) and **Pi^2** (π^2) Pegasi form what Webb called a "grand pair." Having a spread of 15 minutes of arc in an east-west direction, this yellow pair is also a fine sight in small richest-field telescopes.

Look about 4½° north of Zeta Aquarii for the close binary system **37 Pegasi**. The two components, at sixth and seventh magnitudes, are in a very elongated orbit viewed nearly edge-on. The orbital period is about 150 years, and greatest separation (of 1.1") occurred in 1960. The current distance is just under one second (at position angle 118°), making this duo a difficult pair to split.

At the apex of a triangle whose base is defined by Eta (η) and the apparent Pi double is **NGC-7331**, a 10th magnitude spiral galaxy seen almost edge-on. Measuring about 10′ by 2′ in size, it is best picked up by sweeping with a low-power eyepiece on the telescope itself rather than using the finder. Classic observers had virtually nothing to say about this overlooked galaxy, and apparently it gets little attention today as a result. Yet it is brighter than some of the galaxies in Messier's list, and easily found in its isolated splendor.

NGC-7331 serves as a guide to one of the most difficult of all deep-sky objects, even for experienced observers. This is the famed grouping of five galaxies known as **Stephan's Quintet**, discovered visually many years ago with a 30-inch reflector in France. Situated ½° southwest of the previous object, the Quintet can be found by placing NGC-7331 in the northeast quadrant of a 1° eyepiece field and looking in the southwest quadrant. But even then, Stephan's Quintet has eluded many who have searched for it. Its brightest member is the 14th magnitude NGC-7320, and the other members of the tight group (NGC-7317, NGC-7318A and B, and NGC-7319) are much fainter and require at least a 16-inch telescope. These remote galaxies seem to be an "exploding" system whose members are expanding away from each other.

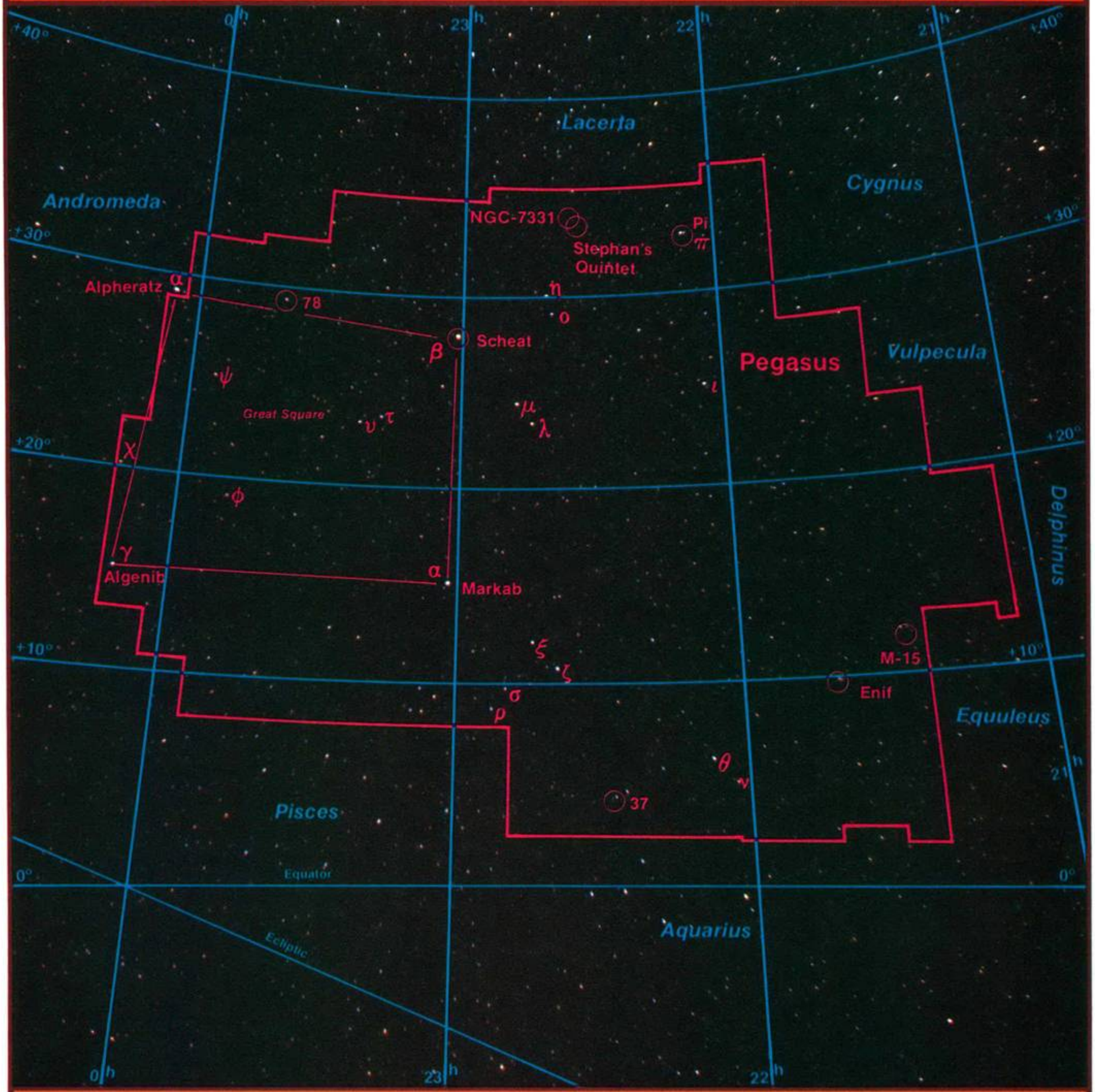
Beta (β) **Pegasi**, also known as **Scheat**, marks the northwest corner of the Great Square. This red M-type star has been observed to vary in magnitude from 2.1 to 3.0, but no regular period has been detected. A red giant star, Sheat would nearly fill the Earth's orbit. What do you estimate its magnitude to be tonight? Compare it to Alpha (magnitude 2.50), Gamma (2.84), and Alpha Andromedae (2.15), the other stars forming the Great Square.

Our final selection in Pegasus is the close double star **78 Pegasi**, consisting of fifth and eighth magnitude suns only one second of arc apart in position angle 245°. This common proper motion pair can be compared with 37 Pegasi — which do you find to be the more difficult duo to split?

pegasus

Map by Dewey Schwartzenburg

Photo by R. Provin & B. Wallis



0h
23h
22h
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+30°
+20°
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Lacerta
Andromeda
Cygnus
NGC-7331
Stephan's Quintet
Pi
π
Alpheratz
α
78
η
o
Scheat
β
Pegasus
Vulpecula
ψ
Great Square
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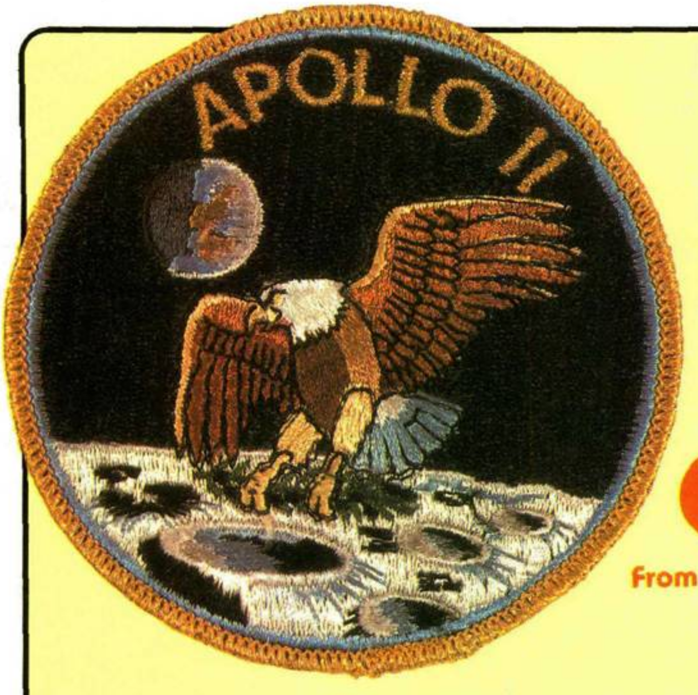
Pisces
Equator
Aquarius
Ecliptic

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.	R.A. (1981)	Dec.
M-15	●	6.0	7′	21 28	+11°57′	21 29	+12°05′
Epsilon (ϵ)	★^{2}	2.5,8.7	143″	21 42	+09°39′	21 43	+09°47′
Pi^1,Pi^2 (π^1,π^1)	★^{2}	4.4,5.6	15′	22 08	+32°56′	22 09	+33°05′
37	★^{2}	5.7,7.0	1″	22 27	+04°11′	22 29	+04°20′
Stephan's Quintet	§0/S			22 34	+33°42′	22 35	+33°52′
NGC-7331	§S	9.7	10′x2′	22 35	+34°10′	22 36	+34°20′
Beta (β)	∩★	2.1-3.0	--	23 01	+27°49′	23 03	+27°59′
78	★^{2}	5.0,8.1	1.0″	23 41	+29°05′	23 43	+29°15′

★	*Star*
★^{2}	*Double Star*
★^{3}	*Triple Star*
m★	*Regular Variable*
∩★	*Irregular Variable*
ꓘ★	*Eclipsing Variable*
○	*Open Cluster*
●	*Globular Cluster*
■	*Planetary Nebula*
□	*Bright Diffuse Nebula*
§0	*Elliptical Galaxy*
§S	*Spiral Galaxy*
§ʃ	*Barred Spiral Galaxy*
§#	*Peculiar/Irregular Galaxy*



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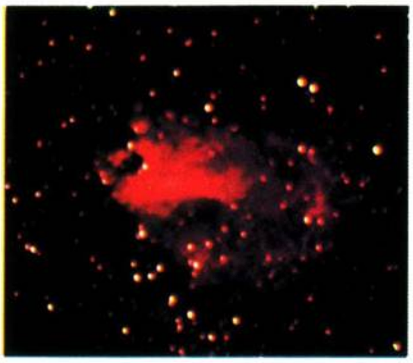
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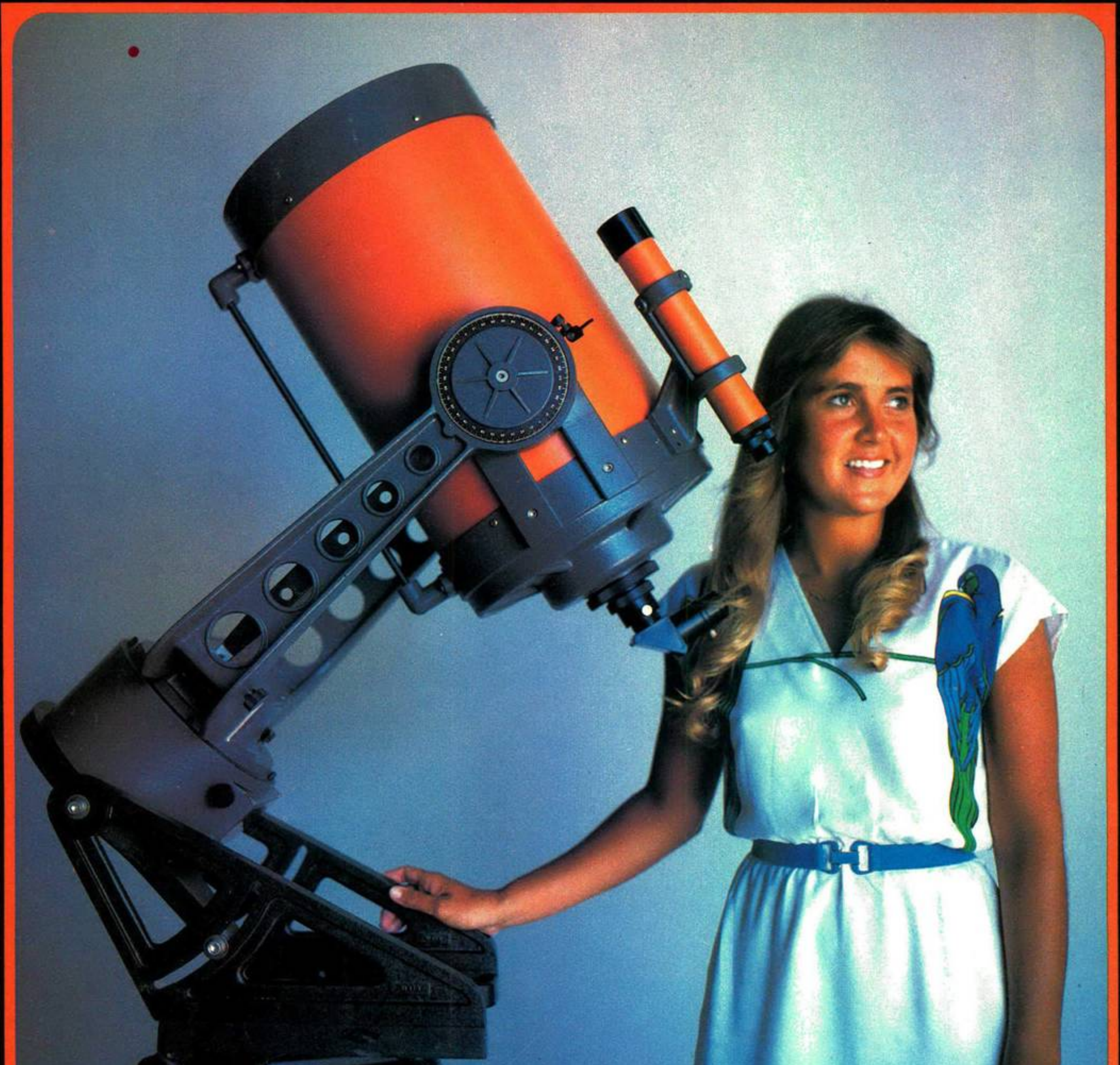

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